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A SURVEY OF ENFORCEMENT PRACTICE WITH RESPECT TO NOISE CONTROL REQUIREMENTS IN BUILDING CODES IN A NUMBER OF EUROPEAN COUNTRIES

Theodore J. Schultz

July 1976
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Prepared for:
Environmental Protection Agency
Office of Noise Abatement and Control
Washington, D.C.
Attention: Cosimo Caccavari

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50 Moulton Street
Cambridge, Massachusetts 02138

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1. INTRODUCTION

It is generally conceded that, although noise control requirements are included in the building codes of a number of countries, these requirements are not very successful in preventing complaints of inadequate privacy from the tenants of the buildings to which the codes apply.

In part, this failure can be attributed to the fact that the masking effect of background noise is not taken into account in the codes, and thus, a construction that would be entirely satisfactory in a noisy urban neighborhood would give rise to serious complaint in a quiet suburb.

In addition, it is not feasible in a code requirement to account for all the different life styles in a community. A family with many noisy children (or other noisy activities) may not even notice the noise coming from next door; but if the tenants happen to be an elderly couple of quiet habits, they may hear and complain bitterly of the neighbors' noise. The same building construction cannot make everyone equally satisfied with his privacy.

Nevertheless, the fact is that in many cases the architect *has* chosen appropriate building constructions which should satisfy the tenants at least most of the time, and still there are complaints. The question is why?

The answer is not hard to find. Hardly anyone disputes that if a reasonably good structure was selected in designing the building and, nevertheless, there are serious noise problems, then something must have gone wrong in the process of constructing the building... something that the building code, as written, and the normal practices of the enforcement agency were powerless to prevent. Either the code specified the wrong acoustical properties for the building, or it was ineffectively enforced.

In order to come to a better understanding of some of these problems, the author has visited a number of European countries where noise requirements in the building codes have been accepted as a matter of course for many years. In interviews with the people actively concerned with the codes and their enforcement, the various approaches taken by different countries were explored by means of a questionnaire, reproduced here as Appendix C.

The results of those interviews, supplemented by subsequent correspondence and discussion, and by the contemporary literature, are presented in this report.

It will become evident that the countries represented fall into two rather sharply defined groups: those that have been active in enforcing the noise control requirements in one way or another, and those in which support for adequate enforcement has not been found. Naturally, the responses to the interview/questionnaire from the latter group were few and rather general. For our present purposes, we have more to learn from the "active enforcement" group. For this reason, the detailed responses on code enforcement from these two groups of countries are presented *separately*, in Appendix B, beginning (in alphabetical order) with the more active countries: Denmark, France, The Netherlands, Sweden, The United Kingdom, and West Germany. The second group includes Austria, Belgium, East Germany, Japan, U.S.S.R., Spain, Switzerland, and The United States. No information is available for countries not mentioned here.

Appendix A presents, for the countries named above and also for certain countries of Eastern Europe, descriptions of the *contents* of the codes; that is, the kind of assessment criteria used for sound insulation in the various countries, and also the requirements for sound insulation specified in the codes.

Many of the codes have requirements on the maximum acceptable indoor noise levels (some focus on the noise generated by equipment in the dwelling or in the building; a few are also concerned with noise from outdoors). All the codes have requirements on airborne sound insulation (or isolation) and impact sound insulation.

These quantities are always specified for dwellings, but in many of the codes requirements are also given for other kinds of buildings: hotels, offices, schools, etc.

Because this report is not primarily concerned with the contents of the codes themselves but with the means of enforcing them, Appendix A makes no attempt to cover all of the noise control requirements in the codes, instead, it presents only the typical airborne and impact insulation requirements for dwellings. Even so, where a code goes into great detail concerning different kinds of space within the dwelling, it did not seem useful to present the entire array of requirements. Thus, attention is confined to the principal living spaces, such as living rooms, bedrooms, kitchens, and baths.

Appendices A and B, dealing with code content and code enforcement, respectively, present the collected information in considerable detail. The main body of this report attempts to form certain generalizations from those details; it focuses upon two especially interesting enforcement approaches, and draws tentative conclusions intended to provide guidance in the framing of noise control requirements for a new model building code for the United States.

For this purpose it will explore the nature of the requirements in the various codes, compare their similarities and differences, examine the means of enforcing the requirements, and attempt to evaluate their effectiveness.

The key word here is "effectiveness," because we wish to discover, if possible, what it takes to make such noise control requirements work.

An obvious approach for judging the effectiveness of a given code would be to conduct a program or field tests of acoustical performance in buildings BEFORE the code requirements are adopted; and then to repeat the tests later, on buildings erected after the code is in force, in order to see what, if any, improvement has been achieved.

So far, no country has yet carried out such an organized study to completion. In fact, unfortunately, the available field data on the acoustical performance of buildings are scarce, scattered, and not well organized; but certain conclusions can be drawn from the rather sparse information at hand.

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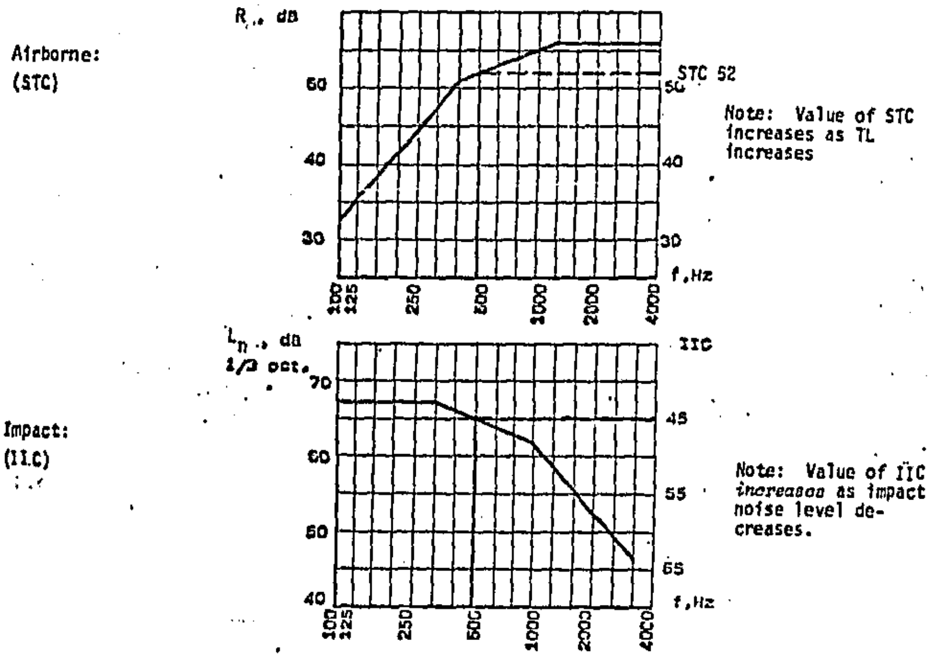
2. EXISTING BUILDING CODE NOISE REQUIREMENTS

The assessment of airborne and impact noise performance, in all the codes with the exception of France, is made by comparing a measured curve of transmission loss (or noise reduction or impact noise) against a reference curve, which is regarded as representing more or less adequate acoustical performance. In one way or another, the differences between the reference curve and the measured curve are used to calculate a single-number rating. The codes then state their acoustical performance requirements in terms of the single-number ratings. (See Appendix A for a more detailed discussion.)

In North America, we use the familiar Sound Transmission Class and Impact Insulation Class (STC and IIC), as shown in Fig. 1. The reference curve for STC (for example) is translated up or down until it matches the curve of measured data, according to certain prescribed rules, at which point the STC for the wall is read off as the value of the shifted reference curve at 500 Hz.

Similar rules are used for calculating the acoustical ratings in most other countries, though some countries, such as Belgium, the United Kingdom, and Rumania, assign "categories" rather than numerical ratings. Figure 2 shows a comparison of the reference curves of several countries. They are similar in shape for the most part but they differ significantly in absolute level. Moreover, the curve-fitting rules permit different allowed deviations. It is difficult, therefore, to compare directly the code requirements against one another.

For comparison of the airborne noise requirements, the following procedure was used. Pink noise was assumed in the source room, at 80 dB in each octave band, and the corresponding A-weighted sound level was calculated. Then the



Note: Value of STC increases as TL increases

Note: Value of IIC increases as impact noise level decreases.

FIG. 1. REFERENCE CURVES FOR AIRBORNE (STC) AND IMPACT (IIC) NOISE USED IN NORTH AMERICA.

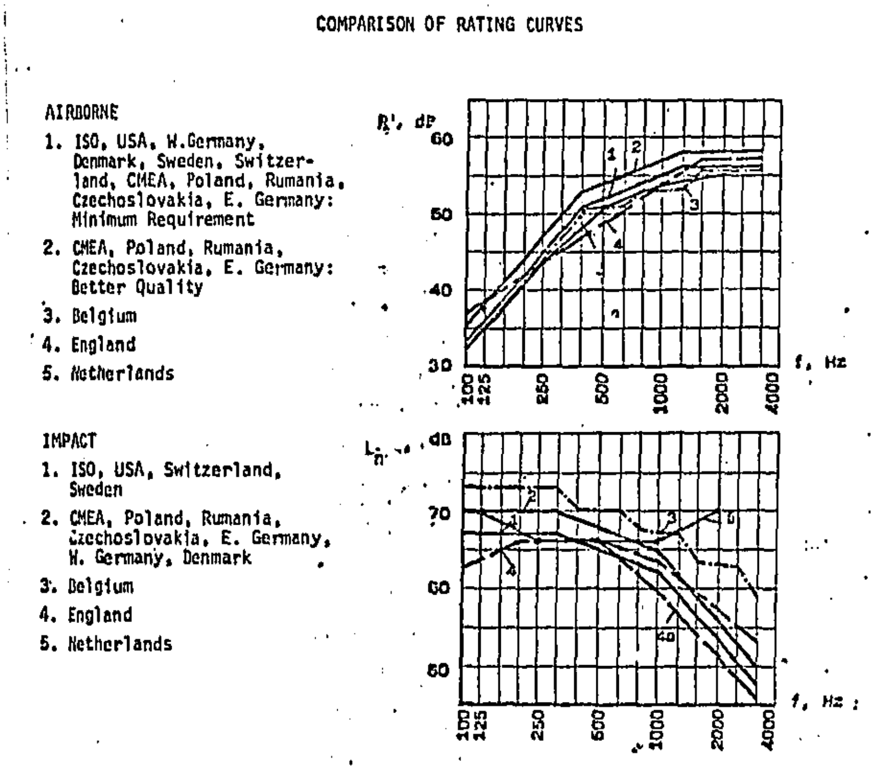


FIG. 2. COMPARISON OF AIRBORNE AND IMPACT NOISE REFERENCE CURVES FROM VARIOUS COUNTRIES. THEY ARE SIMILAR TO ONE ANOTHER IN SHAPE, EXCEPT FOR THE IMPACT NOISE CURVE FOR THE NETHERLANDS.

NR values represented by the reference curve were subtracted from the source room sound levels, band by band, to get the receiving room sound levels, from which were calculated the corresponding A-weighted levels. The difference in A-weighted levels in the source and receiving rooms is the measure of protection against airborne noise required by the code. For impact noise, the A-weighted level corresponding to the reference curve was calculated.

The results are shown in Fig. 3, for the various countries studied.

Many codes have different requirements according to the types of rooms involved. We restrict our attention here to the requirements for bedroom-living room combinations. Column 2 indicates the quantity measured: either the transmission loss (R) or the normalized noise reduction (D_N). Column 3 gives the symbol of the single-number rating used in each case. (For more details see Appendix A.) There is a tendency for Western European countries to follow the lead of the International Standards Organization (ISO), with airborne and impact indices I_a and I_i, whereas in Eastern Europe most countries follow the Council for Mutual Economic Aid (CMEA), with indices E_L and E_T.* Columns 4 and 5 give the minimum and maximum noise control requirements as actually stated in the codes for airborne sound, whereas columns 6 and 7 give the corresponding equivalent requirements in terms of A-weighted sound levels, calculated for this report for the purpose of readily comparing the code requirements. (See Sec. A.3.8 of Appendix A.) Noise control requirements for impact noise, as stated

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*The subscripts L and T stand for the German words luft (air) and tritt (footstep).

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Country	Quantity Measured	Airborne Sound Insulation					Impact Noise Insulation				
		Kind of Rating	Code Requirements		Equivalent ΔL_A(pink)		Kind of Rating	Code Requirements		Equivalent L_A	
			Min.	Max.	Min.	Max.		Min.	Max.	Min.	Max.
Belgium	R D_N	Categories I - IV	II-5 dB II-3 dB	II • o	52 54	57 57	Categories I,II,III	III+3 dB	III	<77	<74
Denmark	R D_N	$I_a\{^{R}_{D_N}$	52 50.	— -	52 50	—	I_i	57	—	<59	—
France	D_N	D_{nA}	51	57 o	51	57	L_A	<70 dBA	<67 dBA	<70	<67
West Germany	R	LSM	0	+3 o	51	54	TSM	+3	+13	<68	<58
Nether-lands	R	I_{lu}	0	+5 o	51	56	I_{co}	0	+5	<73	<68
Sweden	R	I_a	52	— -	52	—	I_i	63	—	<65	—
Switzer-land	R	I_a	50	55 o	50	55	I_i	65	55	<67	<57
England	R	Grades I & II	II	I o •	48	53	Grades I & II	II	I	<71	<65
USA	R	STC	50	57 †o •	50	57	IIC	53	60	<64	<57
ISO	R	I_a	—	— -	—	—	I_i	—	—	—	—
Czech	R	E_L	-1	+2 •	50	53	E_T	0	+10	<71	<61
East Germany	R	E_L	-1	+2 o	50	53	E_T	+4	+14	<67	<57
Poland	R	E_L	-1	— x	50	—	E_T	0	—	<71	—
Rumania	R	Categories R_1 - R_6	R_1	R_5 o	50	52	Categories L_1 - L_5	L_1	L_5	<71	<65
CMEA	R	E_L	-1	+2 o	50	53	E_T	0	+10	<71	<61

o - Different requirements depend on the acoustic quality desired.
• - Different requirements depend on the type of rooms involved.
† - Different requirements depend on the noisiness of the neighborhood.
x - Different requirements depend only on the size of the receiving room.

FIG. 3. ACOUSTICAL INSULATION REQUIREMENTS BETWEEN LIVING ROOMS AND BEDROOMS IN APARTMENTS (PARTY WALL AREA OF APPROXIMATELY 10 m^2).

in the codes, are given in columns 8 and 9, and the A-weighted sound level equivalents in columns 10 and 11.

For airborne sound, the range of minimum requirements is 48 to 54 dBA; for maximum requirements it is 52 to 57 dBA.

For impact noise, the range of minimum requirements is 77 down to 59 dBA; the range of maximum requirements is 74 to 57 dBA. (The requirements shown for the United States are those contained in the Minimum Property Standards of the Federal Housing Administration.)

Figure 4 shows the distribution of these code requirements. The minimum *airborne* noise requirements for the U.S.A are near the low end of the range, but are typical. The U.S.A minimum impact noise requirement is seen to be rather strict in comparison with the others. The United States maximum requirements, both airborne and impact, are quite strict compared to the others.

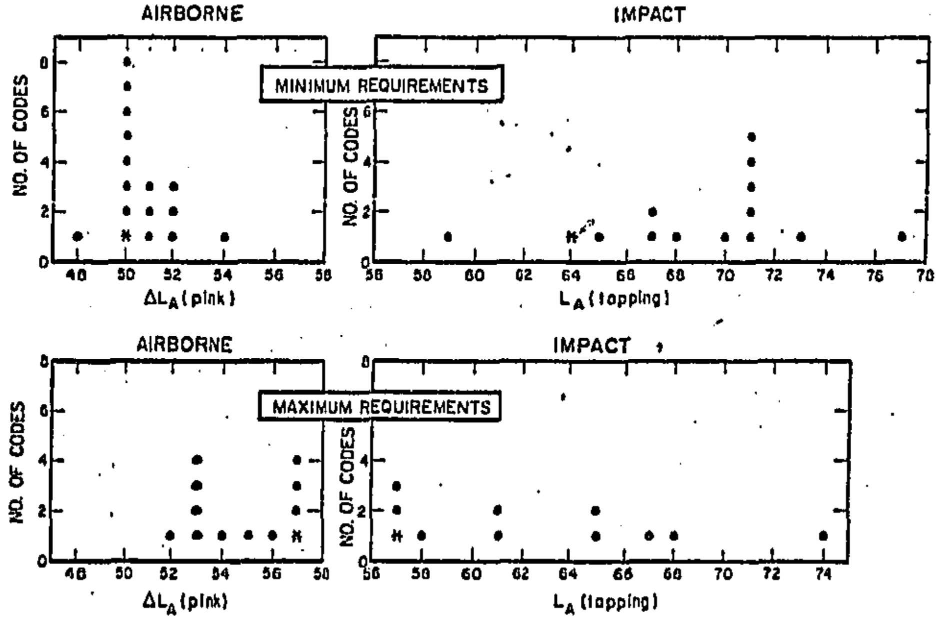

FIG. 4. DISTRIBUTION OF ACOUSTICAL INSULATION REQUIREMENTS BETWEEN LIVING ROOMS AND BEDROOMS IN APARTMENTS (* = U.S.A).

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3. ENFORCEMENT METHODS

We have seen in the previous section various noise control requirements in building codes. But a code requirement is no better than its means of enforcement. Let us look, therefore, at some of the methods adopted for enforcing the various noise codes, as shown in Fig. 5. (Note the key at lower left.)

(Row 1) • Almost all countries rely on required inspection of the building drawings, before issuing the permit to build.

(Row 2) • Most also suggest, or require, approved types of constructions, that are known from experience (or previous measurements) to provide reasonable performance.

(Rows 3 and 4) • Two countries (France and The Netherlands) have tried to improve the acoustic performance in their buildings by providing some kind of financial bonus for improved performance, or by providing a framework for exploiting the market advantage of better sound isolation. (We shall return to the French program later.)

(Row 5) • In two countries (W. Germany and Denmark), there have been isolated examples where the rent was ordered reduced, because of poor sound isolation.

(Row 6) • In many countries, at least some acoustical testing is done in the finished building.

(Row 7) • Remedial measures to correct faulty sound insulation are undertaken only if the failure to meet code requirements is quite serious; and, again, only in Government-financed projects, as a rule.

Procedure \ Country	Belgium	Denmark	France	W. Germany	Netherlands	Sweden	Switzerland	U.K. (4)	USA	Czech.	E. Germany	Poland	Rumania
1. Inspection of drawings	?	xo	(1) xo	xo	xo	xo	?	xo	xo	?	xo	?	?
2. Suggestion (or Requirement) to Use Approved Constructions		x		x	x	x	x	x	x		x		
3. Exploiting Market Advantage			(2) x										
4. Giving Financial Bonus for Higher Quality			(2) x		(3) Δ								
5. Imposing Market Penalty (Lowered Rent)		o		o									
6. Test in Finished Building to Demonstrate Compliance	?	Δ	(2) • o	Δ (3) •	o (<1%)	Δ	?	o ✓			Δ		
7. Corrective Measures if Building Fails Test		Δ ✓		Δ ✓	o	•					o		
8. Pilot Test of Novel Constructions				•	Δ	•		Δ			Δ		

Key: x = Officially required, permitted, or provided.
o = Always or usually done.
Δ = Sometimes done.
✓ = Done only when complaints arise.
• = Seldom done.

(1) = Applies only to Government Subsidized Homes (HLM); no requirements in other buildings, and sound insulation is usually poo..
(2) = In cases where the Acoustic Comfort Label is required.
(3) = If built with Government loan.
(4) = Except inner London.

FIG. 5. MEANS OF ENFORCING CODE REQUIREMENTS.

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(Row 8) • There may also be pilot tests of novel construction to demonstrate compliance with the code requirements. But this is true only in buildings financed by the Government (10 to 25% of the total number of buildings built per year).

In most countries, even those in which noise requirements have existed for many years, it is only in the last 5 to 8 years that people have begun to take the enforcement of these regulations seriously.

4. TWO ENFORCEMENT APPROACHES OF SPECIAL INTEREST

The approaches to code enforcement in various countries are detailed in Appendix B. Here, we concentrate on two countries that have adopted interesting approaches to enforcement: West Germany and France. One aims at success by means of very vigorous enforcement, the other by means of monetary premiums and market advantage. These approaches are not mutually exclusive; in fact, they have common aspects in practice. Both rely on test measurements in the finished building.

4.1 West Germany

There is no nationwide building code noise requirement that applies over all of Germany. Instead, there is a National Standard (DIN 4109) that contains quantitative requirements for noise control in buildings, and specifies both minimum acceptable levels of performance, as well as a higher quality of performance. This DIN standard is not Law.

But each German State has a building code that, instead of specifying numerical requirements of acoustical performance, uses phrases like "sufficient noise isolation" or "must be state-of-the-art." Concurrently, however, another Ministerial Order defines the National DIN Standard as "state-of-the-art," and it thus effectively becomes law, even if by way of the back door.

(Incidentally, there is a great deal of practical advantage to this approach, since it is not necessary to change the law in all the German States, in order to introduce improvements in the measuring methods, or in the numerical code requirements. It is much easier to change the National Standard, for this makes the change automatically effective in all the States.)

Describe the enforcement
What type of penalty

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The minimum German requirements are for: LSM and TSM = 0. The compliance tests are made by about 40 officially designated testing organizations throughout Germany. Each such organization must send its test team to the German National Bureau of Standards every two years, to have its test procedures evaluated and approved.

Figure 6 shows field test results on walls in Bavaria, from 1960 to 1963. There were very few extremely bad results (LSM < -10), and not many very good results (LSM > +10). Most of the buildings, throughout this period, just passed the requirements of LSM = 0.

It is tempting to speculate whether the sudden increase in very good walls in 1963 occurred because the National noise standard on which the Bavarian building code is based was revised and improved in that year.

Figure 7 shows comparable results for impact sound isolation. Because floating floor slabs are almost universally used in Germany, the impact noise isolation is usually very good. Even so, a trend is evident: decreasing numbers of test results in the mediocre categories (-5 to 0) and (0 to 5), and a steady increase in the number of tests in the very good category (> +10).

A similar story emerges in North Germany, as shown in the impact insulation test results in Table I: a steadily diminishing number of failures of the minimum requirement, and an increasing number of buildings complying with the "higher quality" standards. Table II shows comparable results for airborne sound insulation.

The most dramatic comparison is between the poor acoustical quality in the housing built immediately after the war and the housing of some 18 years later, as shown in Fig. 8.

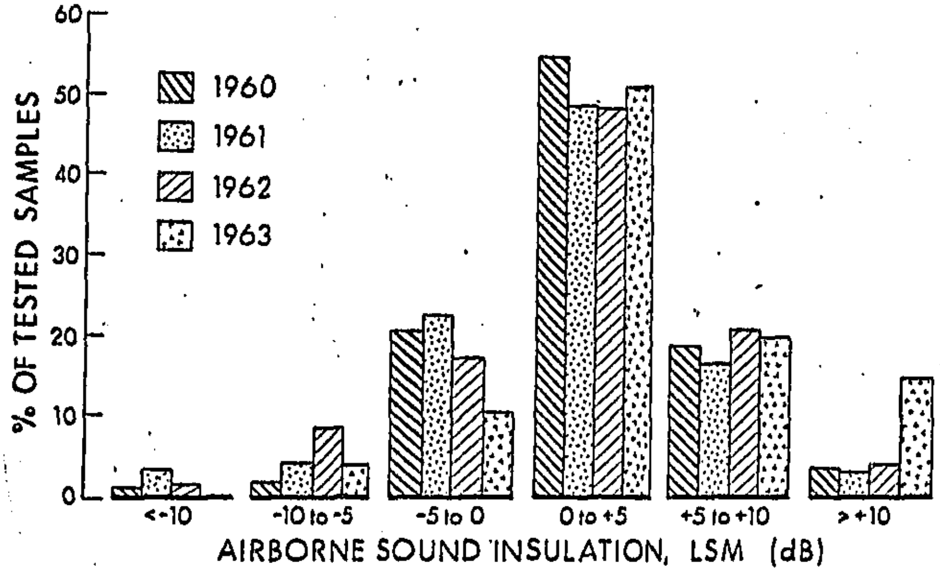

FIG. 6. WALLS: AIRBORNE SOUND INSULATION
FIELD TESTS 1960 TO 1963, MULLER-BBN, MUNICH.

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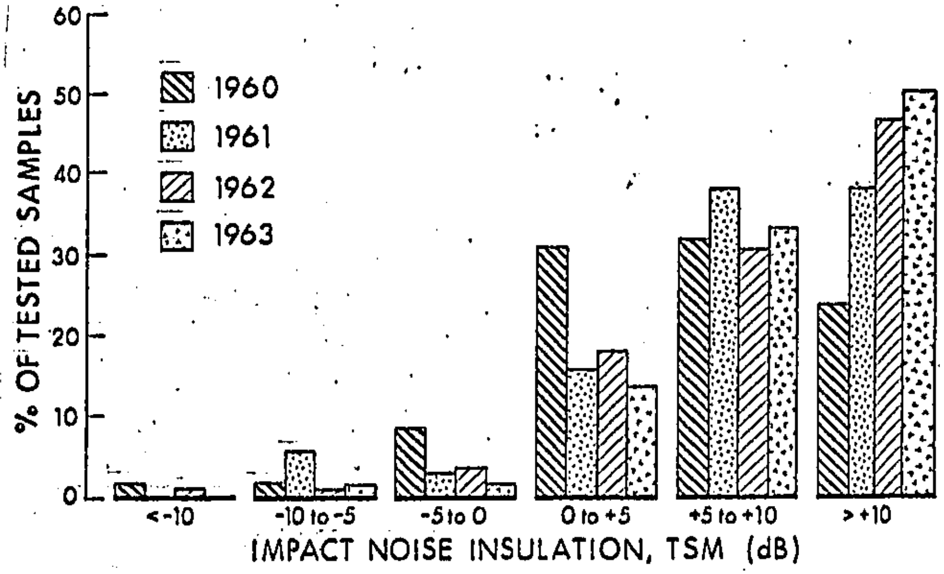

FIG. 7. FLOORS: IMPACT SOUND INSULATION
FIELD TESTS 1960 TO 1963, MULLER-BBN, MUNICH.

TABLE I. GERMAN FIELD TESTS OF SOUND INSULATION

Should be in Tabular form.

Impact Sound Insulation*

Evaluated According to DIN 4109E (January 1959):

Housing Built in:	Failed Minimum Requirement (TSM < 0)	Passed Minimum Requirement (TSM ≥ 0)
1953-1955	28%	72%
1959-1961	14%	86%

Evaluated According to DIN 4109 (September 1962):

	Failed Minimum Requirement (TSM < 3)	Passed Minimum Requirement ($3 <$ TSM ≤ 13)	Passed Higher Grade Requirement (TSM > 13)
1966-1967	7.4%	41.5%	51.1%

*Source: R. Kraege, 1968, about 2000 measurements by PTB, Braunschweig.

TABLE II. GERMAN FIELD TESTS OF SOUND INSULATION

Airborne Sound Insulation (1968)*:

Housing Built in:		Failed Minimum Requirement (TSM < 3)	Passed Minimum Requirement ($3 <$ TSM ≤ 13)	Passed Higher Grade Requirement (TSM > 13)
1966-1967	Walls	26%	49%	25%
	Floors	5%	33%	62%

*Source: K. Gösele, 1973, Stuttgart (Ref. 69).

It must be remembered, here, that compliance tests in Germany have been routinely made only on Government-financed buildings so the data we have seen apply to only some 10 to 25% of the buildings. More important, however, in these projects, the disbursement of the final 1/3 of the construction funds is held up after measurements in the finished

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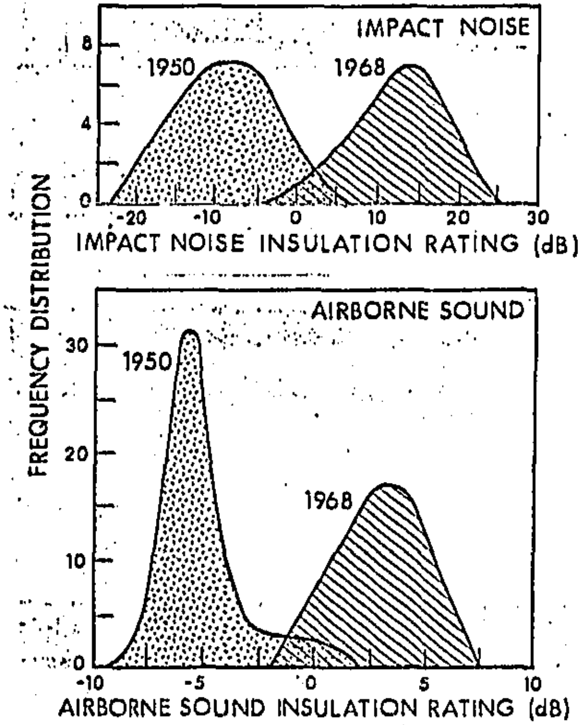

FIG. 8. IMPROVEMENT IN ACOUSTICAL QUALITY IN MULTI-FAMILY DWELLINGS FROM 1950 TO 1968.

building have demonstrated compliance with the code requirements. This approach has "teeth" and it works, at least for the buildings to which it applies.

Why does it have teeth? You have not explained this point yet!

The success of this program in the Government-financed projects, however, has been so great that it has begun to influence the private sector.

For one thing, the building trades who work on the Government-financed projects must learn how to do the job correctly and avoid acoustical mistakes; once the habit is formed, it carries over into non-Government projects. Apparently, it is difficult for the same man to do the same job once well and once poorly.

Moreover, the contractors and builders themselves have become conscientious about complying with the recommendations, and even seek out acoustical advice, themselves, rather than risk being caught and penalized at the end of the project. They tend to feel that the National DIN Standard *does* represent "state-of-the-art," and that it should be followed. In fact, when the Standard was first issued, it was the minimum requirement of the Standard that was aimed for; Today, most builders shoot for the improved level of performance. Moreover, in view of the current inflation, people expect high performance when rental or purchase costs are so high.

Finally, large private building companies, such as Neue Heimat, belonging to the labor unions, have begun, as a matter of course, to have spot checks of the acoustic performance made, to be sure that their builders' work is up to standards.

It appears, from this example, that vigorous code enforcement, particularly with the threat of funds withheld in the event of failure, can lead to wide-spread code compliance. This is, in my terms, "effective noise control"!

- Have funds been withheld?
- How often?
- How much?
- How is it accepted -

4.2 France

It is probably safe to generalize that the French are not so naturally inclined to follow regulations as the Germans, and *that* may be the reason that a different approach was used in France.

The earlier French efforts were based on the usual style of building code enforcement.* Figure 9 shows the French REGULATIONS, that date from 1969; it also shows the more strict requirements for the recently adopted special Acoustic Comfort Label, which we shall return to later. For the time being, the REGULATION requirements (Column 3) may be regarded as minimum code requirements and the LABEL requirement (Column 5) as a "higher quality" requirement. Both are based on measurements in the completed building, and both allow a tolerance of 3 dB for passing the requirements.

which is

Figure 10 shows the cumulative distribution of tests of airborne sound isolation in buildings built between 1960 and 1967, before the Regulation. Only 30% meet the 1969 Regulation (51 dBA), and only 7% meet the Label requirements (57 dBA), without invoking the permitted 3 dB tolerance. *With* the 3 dB tolerance, 54% meet the Regulation (48 dBA), but only 15% the Label (54 dBA).

Figure 11 shows the results of airborne noise tests in buildings built AFTER 1969 under the Regulation. In this case, 70% of the dwellings meet the minimum requirements, though only 25% pass the higher quality Label requirements.

Figure 12 shows the results of impact noise tests in buildings built before 1967. 45% meet the Regulation (70 dBA), but only 28% would pass the Label requirement (67 dBA).

Type of Requirement	Basic Regulation (1969)		Acoustic Comfort Label (1972)	
	Article	Requirement*	Article	Requirement*
Airborne Sound Isolation Between Dwellings	R1	$D_N \geq 51$ dBA	L4	$D_N \geq 54$ to 59 dBA†
Airborne Sound Isolation Between Bedroom and Other Parts of Same Dwelling	--	--	L8	$D_N \geq 44$ to 49 dBA†
Airborne Sound Isolation of Dwelling Facade	--	--	L11	$D_N \geq 33$ to 42 dBA**
Impact Noise Insulation	R2	$L_A \leq 70$ dBA	L5	$L_A \leq 67$ dBA
Noise of Equipment in General, Inside or Outside the Dwelling	R3-1	$L_A \leq 35$ dBA	--	--
Noise of Equipment in General, Located Outside the Dwelling	--	--	L10-1	$L_A \leq 32$ dBA
Noise of Equipment in General Located Inside the Dwelling	--	--	L9	$L_A \leq 30$ dBA
Noise of Collective Building Equipment (Elevators, Heating and Ventilating System, Pumps, Transformers, etc.)	R3-2	$L_A \leq 30$ dBA	L10-2	$L_A \leq 25$ dBA

*Both the Regulation and the Label allow a tolerance of 3 dB for passing the requirements.

†Depending on the rooms involved.

**Depending on the outdoor noise levels.

FIG. 9. FRENCH NOISE CONTROL REQUIREMENTS.

AIRBORNE SOUND ISOLATION BETWEEN DWELLINGS

Number of Tests: 570

Comment: 30% of the tests meet the 1969 Noise Control Regulation without invoking the permitted 3 dB tolerance, but only 7% would meet the Label requirement.
54% of the tests pass the Regulation with the tolerance, but only 15% would pass the Label requirement.

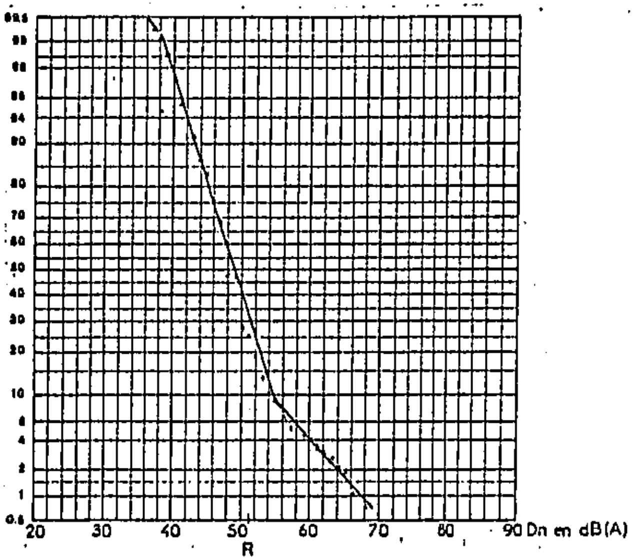

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FIG. 10. DISTRIBUTION OF TESTS RESULTS IN FRENCH FIELD TESTS (1960-67) OF NOISE ISOLATION.

AIRBORNE SOUND ISOLATION BETWEEN DWELLINGS [Article R1 (L4)]

Number of Tests: 480

Comment: 45% of the tests met the Regulation without invoking the permitted 3 dB tolerance, but only 10% met the Label requirement.
70% of the tests passed the Regulation with the tolerance, but only 25% passed the Label requirement.

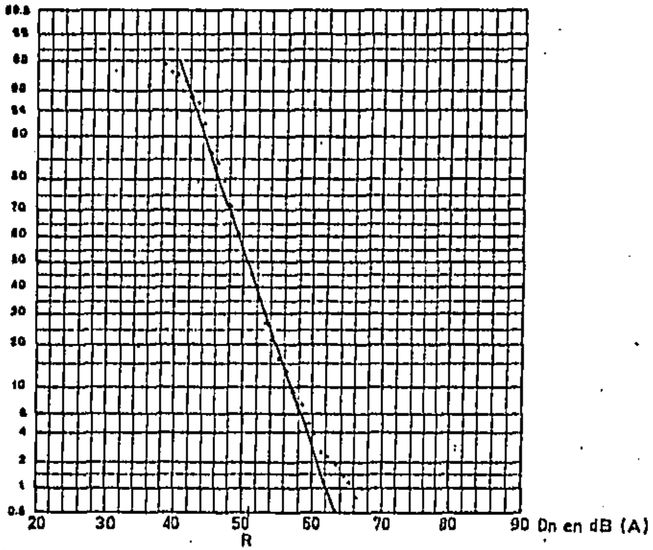

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FIG. 11. DISTRIBUTION OF TEST RESULTS IN FRENCH FIELD TESTS (1969-72) OF NOISE ISOLATION.

IMPACT NOISE INSULATION BETWEEN DWELLINGS

Number of Tests: 283

Comment: 28% of the tests meet the 1969 Noise Control Regulation without invoking the permitted 3 dB tolerance, but only 13% would pass the Label requirement.
45% of the tests meet the 1969 Regulation with invoking the permitted 3 dB tolerance, but only 28% would pass the Label requirement.

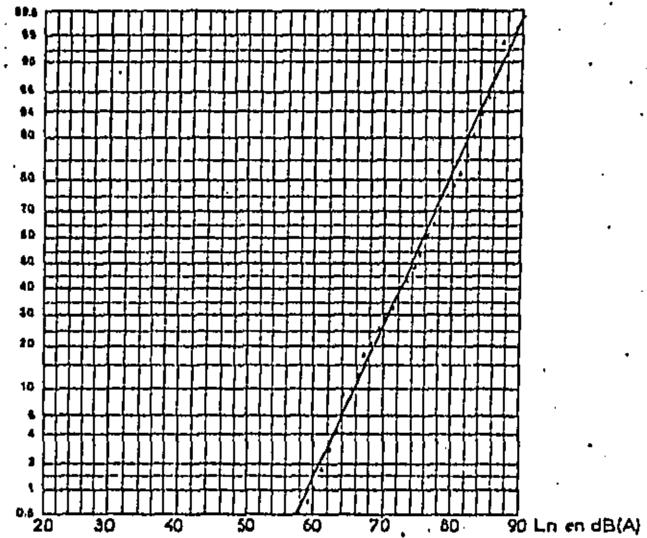

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FIG. 12. DISTRIBUTION OF TEST RESULTS IN FRENCH FIELD TESTS (1960-1967 OF NOISE ISOLATION

Figure 13 indicates that the impact test results for the post-1969 dwellings show no improvement over the earlier results: 46% and 26%, respectively.

All in all, this was not regarded as a satisfactory record.

In 1972, a new approach was adopted in France, in terms of the so-called Acoustic Comfort Label. An owner whose building is awarded this Label benefits in two ways, First, he may advertise that his building has superior acoustical performance, certified with one, two, or three stars, in increasing order of quality. And, second, the amount of his loan from the Government, for the purpose of building the project, is increased according to the demonstrated quality of the sound isolation.

Figure 14 summarizes the evaluation procedure.

Points are awarded according to whether the building meets the Acoustic Comfort Label requirements in five categories, as shown in the left column. The airborne sound isolation rating, for example is stated in terms of the A-weighted sound level in the receiving room (29 dBA for LR or BR) (Column 2) when there is a specified SPL in each octave band in the source room (80 dB/OB for LR or BR) (Column 3). Up to 3 points can be awarded for the airborne sound isolation between dwellings.

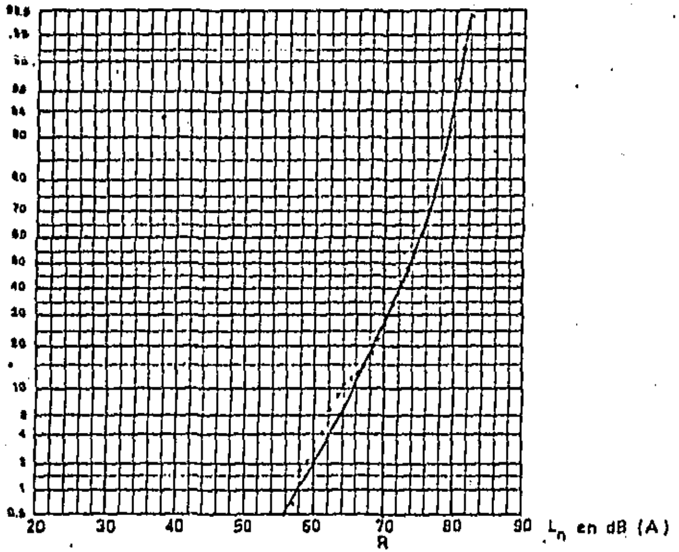
The maximum number of points that an apartment building can win is 20. The requirements of the 1969 REGULATION must be met; the points are awarded on the basis of whether or not the higher quality requirements of the label are also met.

No label is given in the building scores less than 8 points. The Label with one star is awarded if it get 8

IMPACT NOISE INSULATION [Article R2 (L5)]

Number of Tests: 296

COMMENT: 26% of the tests met the Regulation without invoking the permitted 3 dB tolerance, but only 14% met the Label requirement.
46% of the tests passed the Regulation with the tolerance, but only 26% passed the Label requirement.



CENTRE SCIENTIFIQUE ET TECHNIQUE DU BATIMENT, 4, Av. du Recteur Poincaré, PARIS - XVI°.

FIG. 13. DISTRIBUTION OF TEST RESULTS IN FRENCH FIELD TESTS (1969-72) OF NOISE ISOLATION.

RULES
No Label: <8 pts.
1 Star: 8 - 14 pts.
2 Stars: 15 - 19 pts.
3 Stars: 20 pts.

	Maximum Permissible Sound Level		Possible Number of Points Awarded
	In the Receiving Room:	When the noise is emitted in:	
Airborne Sound Isolation Between Dwellings	Any main dwelling room: 32 dBA	Any main dwelling room of same type: 80 dB/OB	3
	Nearest Bedroom: 27 dBA	Bath, Kitchen 80 dB/OB	
	Living Room: 29 dBA	Bedroom 80 dB/OB	
	Bedroom: 29 dBA	Living Room: 80 dB/OB	
	Living Room: 29 dBA	Bath, Kitchen: 80 dB/OB	
	Bedroom: 29 dBA	Corridor: 70 dB/OB	
	Living Room: 32 dBA	Corridor: 70 dB/OB	
	Main Dwelling Room: 32 dBA	Commercial or industrial spaces, garage, public areas: 85 dB/OB	
Airborne Sound Isolation Within the Dwelling	The part of the dwelling reserved for sleep: 35 dBA	Other parts of the same dwelling: 70 dB/OB	2
Impact Noise Insulation	Main dwelling room: 67 dBA	Any room, tapping machine on the floor	4
Equipment Noise	Main dwelling room: 25 dBA	In any part of the building outside the dwelling, by collective equipment (elevators, central heating, etc.)	3
	32 dBA	All other equipment	2
	30 dBA	Individual equipment in any part of same dwelling	1
Traffic Noise	Room exposed to noise: Isolation of 42 dBA 33 dBA —	Outdoors: Zone I: $L_A > 73$ dBA Zone II: $63 < L_A < 73$ dBA Zone III: $L_A < 63$ dBA	} 5 —

Building loan is increased by 0.325% for each acoustic point awarded to the finished building.

Possible Total = 20 Points

FIG. 14. EVALUATION OF ACOUSTICAL PERFORMANCE FOR FRENCH "ACOUSTIC COMFORT LABEL".

to *14* points, two stars if *15* to *19* points, and three stars if it wins all *20* points.

In addition, the building loan is increased by 0.325% for each point won, for a possible total increase of 6.5% of the basic building cost.

For comparison, Fig. 15 shows the approximate cost of acoustical treatment to meet the 1969 Regulation in France in the year 1970.

Figure 16 shows the approximate cost of acoustical treatment in attempting to achieve the Acoustic Comfort Label in a pilot project used in developing the Label program. It is not known what actual percentage of the building cost this represents. But if one assumes a building cost of $15 per sq ft, the acoustical treatment would be about 5% of the total cost, a figure that is not far from comparable estimates in the U.S.A.

As for the cost of monitoring noise control requirements, examination of the drawings costs 1200 F or $240.00; and acoustical tests, in a project of 200 units (80 tests), cost 13000 F or $2600.00 in 1972.

The Acoustic Comfort Label is apparently having a beneficial effect on the sound isolation of French dwellings, but there are no statistical data yet to confirm this. It is expected that the combination of increased money and favorable publicity would provide an effective incentive for better buildings.

If planned from the beginning:	2% of total building cost
If introduced to correct mistakes or omissions during construction:	6 to 7%
After building is finished:	15 to 25%, and with no guarantee of success

Reference: Centre Scientifique et Technique du Batiment, Cahier 943 (#108), April 1970; p. 25.

FIG. 15. COST OF ACOUSTICAL INSULATION IN FRANCE (1970).

Noise Abatement Measure	Cost (including taxes) per sq ft of Habitable Space	Percent of Total Noise Abatement Cost
Floating Floor Slab	54 cents	71.24%
Rubbish Chute Treatment	1.4 cents	1.83
Isolation of Plumbing	2.06 cents	2.72
Treatment of Heating and Ventilating System	2.9 cents	3.78
Special Glazing	10.7 cents	14.10
Enclosing the Rolling Shutters	4.8 cents	6.33
TOTAL	76 cents	100%

Reference: Revue d'Acoustique, No. 24 - 1973; p. 47.

FIG. 16. COSTS OF NOISE ABATEMENT IN "OPERATION CREIL" (FRANCE): (1971-73; 86 UNITS).

5. CONCLUDING REMARKS

For the noise control provisions in building codes to be effective in assuring adequate sound isolation in buildings, two conditions must be met: the noise control requirements in the codes must actually be *relevant* to the attainment of adequate sound isolation, and the codes must be effectively *enforced.*

As for the *relevance* of the noise control requirements in existing codes, the ones dealing with airborne sound insulation are needlessly over-complicated (sixteen measurements of level difference and sixteen measurements of sound absorption or reverberant time, calculated down into a single-number rating); and the ones dealing with impact sound insulation are quite wrong (the same value of impact sound rating can be assigned to floors for which subjective judgments span a range of 20 decibels! [*24*]).

As for the *enforcement* of the requirements, it can be seen from the accounts in Appendix B that until the last few years no serious effort has been made anywhere, and even then, only in a few countries.

Paradoxically, although the rating method for impact sound insulation is almost totally irrelevant to the subjective judgments of people with respect to the acoustical quality of the floors, the attainment of adequate insulation against impact noise for floors has been better than for the airborne sound insulation of walls. This has occurred for reasons having to do with structural integrity, rather than the noise control provisions in the building codes.

What are needed, and needed badly, are simple test measurements for both airborne and impact sound that correlate closely with people's judgments of the sound isolation they enjoy in their dwellings. It has recently been shown that a simple measurement of airborne sound isolation based on A-weighted sound levels correlates as well with subjective judgments as the complicated standard test procedure in 1/3-octave bands of frequency [76]. And a modified test method for impact noise insulation has recently been proposed, and is currently being studied in a number of national laboratories, that promises considerably improved correlation with the subjective assessment of impact sound insulation of floors [77]. This test, too, can probably be done with A-weighted sound levels. Both methods will be published soon by the American Society for Testing and Materials (ASTM).

Thus, it is expected that, before long, simple and reliable test methods for both airborne and impact sound insulation will be in the hands of officials charged with the enforcement of noise control requirements in building codes; and these methods will be well within their technical capability and the required test equipment will be within their budgets.

The problem then will be to revise the outmoded noise control requirements in the existing building codes, that call out the sound insulation of specific building elements, and replace them with requirements for the sound isolation between dwellings, with mandatory compliance to be demonstrated in the finished building by means of simple test measurements.

I have, in the past, suggested an analogy that has caught the imagination of a number of people: "It does no good to argue that the basic [building] construction was suitable, as approved in the [building] drawings, if, in fact, one can easily hear through the walls of the finished building. This is as foolish as trying to excuse a bad soufflé on the grounds that the eggs were of top quality!" [2].

Without doubt (as many of my European friends have pointed out) it is important to assure that the eggs are, in fact, of good quality; this implies that the building drawings must show that wall and floor constructions have been chosen that are known from experience or from previous tests, in the laboratory or the field, to be of adequate quality. But the quality of the other ingredients and the skill of the cook cannot be judged until the end.

What would be the point of a Cordon Bleu School of Cuisine in which all the finished dishes were discarded without being tasted? What professor would administer a final exam to his students with the promise that he would not read and grade it?

The function of the specification compliance tests in the finished building is to force the responsible persons to apply the alreading existing technology instead of ignoring it.

The objection has been raised that it is not fair to legislate that a building may not be occupied if it fails to meet prescribed acoustical performance, when even skilled acoustical consultants cannot predict flanking transmission accurately.

In my view, this is beside the point. In the first place, it is abundantly evident that until such strong measures are adopted, *nothing* effective will be done about attaining adequate sound isolation in dwellings. And in the second place, since adequate sound isolation is well within the present state of the art, it will not take long for builders to catch up with construction methods that lead to compliance. If there are a few expensive mistakes in the interim, that is just too bad: tenants have suffered long enough!

One possible approach to the formulation and enforcement of noise requirements in building codes is as follows. It takes advantage of the procedures currently used in most Codes, but goes a step further in requiring assessment of the final result [3].

At the time of application for a building permit, the architect's drawings for the building will be examined to see that he has chosen suitable constructions for the walls and floors. If he has selected structures known from experience to provide adequate noise isolation, the building permit will be issued. However, the permission to build confers only tentative approval of the noise isolation of the building; accepting or correcting the architect's choice of construction at this stage amounts only to guidance based on past experience. Detailed guidance will also be offered at this time on ways to avoid mistakes during construction.

The crucial test comes when the building is completed; a field test of the building must demonstrate that the specified isolation has in fact been achieved.

Here was come to an option. Either the sound isolation itself can be specified in terms of the normalized noise reduction, D_{nt}; or a measure of acoustical privacy, the Privacy Index, can be specified that involves not only the noise reduction, but also the expected or achieved background noise (see below).

In the first case, because the background noise may vary over a wide range and it is not explicitly taken into account, the correlation between the test result and the subsequent tenant satisfaction may be only about 64%. If the background noise level is taken into account, as in the Privacy Index, the correlation improves to 88%.

Privacy, in the proposed code, is determined by the sum of two numbers: the A-level difference, ΔL_A, between the source and receiving rooms, and the A-weighted level, N_A, of the background noise in the receiving room. This sum is called the Privacy Index, I_P*. Measurements in the completed building must demonstrate a value for I_P of at least 75 as a minimum requirement. One or two better grades of privacy (I_P = 80 and 85) could be defined, but not required, for building owners who want to take credit for providing privacy better than the minimum.

The code will formally specify values of sound *insulation* (STC) for the walls and floors, to provide guidance in the design of the building, and to make it simpler when the drawings are to be approved for a building permit. However, if the A-level difference measured in the finished building complies with the code's additionally specified value of *isolation*, then the complicated transmission loss tests [5], including the anti-flanking demonstration, to prove compliance of the *individual* building components with the specified values of STC, would be waived.

To establish the principle of compliance with a performance specification with the least disruption of current practice, we propose a stepwise approach. We first decide how much isolation is ultimately desired for housing, and express this in terms of a certain value of ΔL_A, say X. For the first year or so after the new code in in effect, only those constructions would be approved, at the building drawing examination, that usually yield somewhat better performance than the ultimate goal, say X + 5. Also, at first, when tests are made in the finished building, the building would be approved for occupancy even if it fails to meet the desired goal by, say, 5 dB. (The value of 5 dB is discussable in both cases.) Thus, at first there would be a 10 dB margin for error during construction... approximately what is being achieved at present; no sudden difficulties are imposed on the architect or builder immediately after the code goes into effect.

Gradually (at two or three year intervals), as construction workers learn how to improve their assembly techniques to avoid leaks and flanking, the permitted margin will be narrowed in steps, partly by permitting more "speculative" constructions at the building permit stage, and partly by applying the isolation requirements more strictly in the test in the finished building. After five to seven years a significant improvement in achieved privacy should be realized, in all kinds of dwellings.

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*The Privacy Index has the advantage that no normalization is needed to account for differences in receiving room absorption; the effects on ΔL_A and N_A are equal and opposite.

When it comes to the actual framing of the Code, Ref. 78 is required reading.

This report concludes with Fig. 17: a discouraging reminder of the record of failure that can be expected when no special incentives are offered, to encourage the effective enforcement of building noise control.

Line 3 shows the typical failure rates. As of the time for which these data apply, only the German and Swedish enforcement are very effective. (The French data cited here pre-date the Acoustic Comfort Label.)

It is apparent that effective noise control in our building codes will be achieved only when we require measurements in the finished building, to demonstrate compliance with the code, and either offer a premium for superior acoustical performance or impose a penalty for failing to meet the noise requirements.

This report concludes with a story about a man who bought a mule from an old farmer. When he go the mule home, he found it impossible to make the mule do any work. He would whip it, push it, pull it, persuade it, curse it, shout at it... all to no avail. The mule would not pull the wagon.

So the man took the mule back to the farmer, explained the situation and asked for his money back. The old farmer simply reached down, picked up a very heavy stick, and, as hard as he could, slammed the mule in the face with it.

The mule immediately moved off with the wagon. "First," said the old farmer, "you got to get his attention."

It is suggested here that we don't stand much chance of getting the attention of architects, contractors, builders, and trades, without some form of prize or penalty that depends upon proof that they have done their noise control work well.

Country	Belgium	Denmark	France	W. Germany	Netherlands	Sweden	Switzerland	U.K. (4)	USA	Czech.	E. Germany	Poland	Rumania
1. Percent of Buildings Tested	?	50-60 bldgs. per year (6/71)	?	(1) 5-10%	1% (6/71)	5-15% (2/72)		"Few" (5/72)	Almost 0% (1975)		(2) "Few" (6/71)		
2. Percent of Rooms Tested, in the Tested Buildings?	?	3-20 rooms per bldg. (6/71)	?	>10%	5-10% (6/71)	10-15% (2/72)		≤10% (5/72)	-		10% and (3) 20-50% (6/71)		
3. Percent of Tested Buildings that Fail to Meet Code?	95% (10/71); "Nearly all" (3/72)	≈50% (1970)	50-60% (9/62) 46-70% (1960-67) 30-55% (1972)	"Many" (1962) ≈10% (1975)	40-50% (6/71)	5-20% (2/72)		50% "and increasing" (5/72)	-		30% (6/71)		

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(1) But only for projects built with Government loan; all such projects are tested; otherwise, only a few buildings are tested (e.g., if requested by architect).
(2) Because of limited number (about ten) construction types used.
(3) In experimental building of new type.
(4) Except inner London.

FIG. 17. EFFECTIVENESS OF NOISE CONTROL REQUIREMENTS IN EUROPEAN BUILDING CODES. *The tabulated information was published (or communicated) on the dates shown in parentheses.*

APPENDIX A

ASSESSMENT CRITERIA AND REQUIREMENTS FOR SOUND INSULATION IN VARIOUS COUNTRIES

DRAFT

A.1. INTRODUCTION

Quite a number of countries have noise control requirements in their building codes, specifying the required acoustical performance of either the individual structural elements or the completed building [*1,2,3*]. In most of these codes, the acoustical performance is assessed by comparing a measured curve of transmission loss (or noise reduction, or impact noise) against a *reference* curve which is regarded as representing adequate sound insulation. The differences between the measured curve and the reference curve are used to formulate a single-number rating. The building codes state their acoustical performance requirements in terms of these single-number ratings, usually one for airborne sound insulation and another for impact noise insulation.

A.1.1 Basic Acoustical Measurements

The basic acoustical measurements underlying the code ratings and requirements are, for airborne sound, either transmission loss (to measure the sound *insulation* of a specific building element) or noise reduction (to measure the sound *isolation* between rooms); and, for impact sound, the impact noise level in the receiving room above which a standard tapping machine is being operated.

Usually these quantities are normalized to standard acoustical conditions in the receiving room; that is, the values measured in a specific test situation are adjusted to the values that would have been observed with a receiving room having a standard amount of sound absorption or a standard reverberation time.

The measurements are usually made in 1/3-octave bands of frequency, though octave bands are also permitted in some standards, in the frequency range between (approximately) 100 to 4000 Hz. (The range differs slightly from one country to another.)

DRAFT

A.1.1.1 Sound insulation of a partition [3]

Some codes specify the sound insulation of specific building elements, usually the party wall or floor/ceiling between dwellings (but see Sec. A.1.1.3, below). The sound insulation of a structure is the capability of that particular structure for attenuating sound that is following the path through that structure. It is expressed in decibels in terms of the ratio of the sound energy striking the partition on the side exposed to the sound source to the sound energy passing through the structure and radiated away from the partition on the opposite side. Special effort should be made to eliminate (or to leave out of account) any sound (the so-called flanking transmission) following paths other than the one directly through the structure.

In North America, the sound insulation of a partition is called transmission loss [4,5], with the symbol TL, when the measurements are made in an acoustical laboratory where the flanking transmission has been eliminated by careful construction. In Europe, this quantity is called the sound reduction index, with the symbol R [8,9].

If the sound insulation of a partition is measured in the field, where flanking transmission may exist, the practice in North America [5] is to conduct the measurement in such a way as to eliminate the effects of flanking transmission; the intention is to insure that the resulting data truly refer only to the sound path through the partition that is nominally under test. This quantity is called Field Transmission Loss, with the symbol FTL.

In most of Europe, however, no attempt is made to eliminate flanking transmission in field tests. Instead, the field test is conducted with the same procedure as in laboratory tests. The resulting data (which may involve sound passing to the receiving room by paths other than the party wall) are treated as representing the sound reduction index of the partition "AS IF" all of the sound energy had indeed passed through the party wall. This field sound reduction index* has the symbol R' (an unfortunate choice, since the prime frequently gets lost in poor printing or reproduction of text with the result that R' is often confused with R).

A.1.1.2 Sound isolation between rooms

Some codes specify, instead of the sound insulation of specific individual building elements, the sound isolation between dwellings in the finished building. This quantity takes into account all of the sound arriving in the receiving room by whatever paths, and is a measure both of the acoustical performance of the entire structure and of the degree of acoustical privacy that will be experienced by tenants of the dwellings [3].

In North America, the sound isolation between rooms is called noise reduction [5], with the symbol NR, it is simply the difference in the sound pressure levels in the source and receiving rooms, measured in bands of frequency, when a noise source is operating in the source room. In Europe, this quantity is called level difference, with the symbol D [8,9].

If the values of sound isolation are normalized (as discussed in A.1.1 above), the North American term is normalized noise reduction with the symbol NNR; normalization is to standard reverberation time [5]. The European term is normalized level difference with the symbol D_n; in some cases, an additional subscript is used to signify whether the normalization is to a standard amount of receiving room absorption or to standard reverberation time: D_{na} or D_{nt} [8,9].

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*In the revision of ISO R140 currently under consideration, this quantity is called the "apparent sound reduction index."

A.1.1.3 Sound insulation of a partition vs sound isolation between rooms

Unfortunately, these two concepts have become somewhat confused over the years [3]. Codes that specify sound insulation, in terms of TL or R, do not always explicitly identify which building element is under consideration; it is often assumed that the party wall is intended, and that, if the party wall meets the code requirements, there will be adequate privacy for the tenants of the building. This, of course, will not be true if there is significant flanking transmission.

This confusion is regrettably encouraged by the European use of the "AS IF" measure of sound insulation, R', which measures all of the sound reaching the receiving room but attributes it all to the party wall path, thus mixing the two concepts in one rating.

The intended procedure in enlightened North American practice [3]* is first to assess sound isolation (privacy) achieved in the finished building by measuring the noise reduction between rooms in adjacent dwellings. If that quantity for any reason fails to meet the requirements, then the rather complicated field transmission loss test procedure for measuring the sound insulation of the various specific building elements is used, as a diagnostic tool, to determine which structure is at fault and needs correction.

In Europe, there is no standardized test procedure for field measurements of sound insulation that confines attention to a specific building element. If a measurement of level difference, D, should indicate inadequate sound isolation in the finished building, it does no good to measure the field sound reduction index R', because that quantity attributes *all* of the sound transmission to the party wall. It is astonishing that the European partition manufacturers

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*It must be admitted that "enlightened" in this sense is not yet widespread.

tolerate this manifestly unfair practice, which often blames their own products with the faults of other trades.

A.1.1.4 Impact sound transmission

All countries assess the capability of a floor-ceiling structure to insulate against impact noise by measuring in specified frequency bands the transmission of noise into a receiving room when a standard mechanical tapping machine is operating on the floor overhead [*24*, *25*]: the greater the amount of impact noise transmitted, the poorer the impact insulation of the floor-ceiling structure. The values of impact noise so measured are usually normalized, either to a standard amount of sound absorption or a standard reverberation time in the receiving room.

Impact noise measurements are made in 1/3-octave bands in some countries and in octave bands in others. Great care must be used in interpreting impact noise data, however; this is because some, *but not all*, countries in which the basic data are measured in 1/3-octave bands require these data to be adjusted (by the addition of 5 decibels) to values corresponding to octave-band data [*25*]. Thus, even with a standard test method and a standard tapping machine, the impact noise data for the same floor structure might differ by 5 dB depending on the country where it was measured. This same uncertainty, of course, propagates into the single-number impact noise ratings of the different countries, discussed in the next section. (See Appendix D for more detail.)

A.1.2 Single-Number Ratings and the Criterion Curves

Any one of the basic acoustical measurements discussed above, if it is made in 1/3-octave bands, will yield test results in the form of sixteen separate values of sound pressure level, one for each of the sixteen frequency bands in the range of interest: 125 to 4000 Hz in North America, and 100 to 3150 Hz in Europe. With such an array of data for each test result, it is very difficult to compare the acoustical performance of one structure against another: structure A may be better than structure B in some frequency bands but worse in others: which is better overall?

In order to permit easy comparison of the performance of different structures, all countries have adopted single-number ratings, both for airborne and impact sound, which condense the information embodied in the sixteen band levels into a single number or grade with which to rank-order different structures according to their capability to insulate against airborne or impact sound.

Except in France, the single-number rating is determined by comparing the measured curve of acoustical performance against a reference criterion curve in accordance with a prescribed procedure that delimits the amount of unfavorable deviations. Both the criterion curves and the fitting procedures differ slightly from country to country.

In Western Europe and North America, most countries follow the lead of the acoustical ratings standards set by the International Standards Organization (ISO), Geneva, with only small variations. This includes West Germany, Sweden, Denmark, Norway, The Netherlands, Switzerland, The United Kingdom, The United States, and Canada. Belgium and France use somewhat different approaches: different from ISO and from each other. The single-number indices for airborne and impact sound used in Western Europe are, respectively, I_a and I_i; the values vary continuously along a numerical scale. As the value of the airborne sound insulation index increases, this signifies better sound insulation; as the impact noise index increases, it signifies poorer insulation against impact noise.

In North America, the single-number rating for transmission loss is Sound Transmission Class (STC) [6]; for impact noise, it is the Impact Insulation Class (IIC) [7]. Both ratings increase in value with increasing quality of sound insulation.

In Belgium and The United Kingdom, discrete grades are assigned, rather than a continuously variable index. In France, the data in 1/3-octave bands are converted, by calculation, into A-weighted sound levels, and the single-number ratings are stated as differences in A-levels for airborne sound and A-levels for impact sound.

In Eastern Europe, most countries follow the standards of the Standing Building Committee of the Council for Mutual Economic Aid (CMEA). This includes Poland, Czechoslovakia, Rumania, Finland, East Germany, and the USSR.

In most of Eastern Europe, the indices for airborne and impact sound insulation are the airborne sound insulation index, E_L, and the impact sound index, E_T. These are continuously variable indices, but they are not the same as the ISO indices, I_a and I_i; rather, they resemble more closely certain forms of sound insulation indices used until recently in West Germany: the Luftschall Schutz Mass (LSM) and Trittschall Schutz Mass (TSM). Rumania, however, differs from the others by assigning discrete grades; as in Belgium and The United Kingdom, the acoustical performance ratings increase stepwise, rather than continuously.

One can, with some difficulty, get information about the ratings and requirements for acoustical performance in the building codes of Eastern European countries, but it is practically impossible to learn the effectiveness of these requirements in providing satisfactory sound isolation in the finished buildings. Typically, the buildings are designed, built, owned and tested (if at all) by the State; little published information on the test results reaches the United States.

A.2 ACOUSTIC PARAMETERS, ASSESSMENT CRITERIA AND REQUIREMENTS FOR ACOUSTICAL PERFORMANCE IN BUILDING CODES IN VARIOUS COUNTRIES

The International Standards Organization (ISO) and the Western Countries

A.2.1 International Organization for Standardization [8,9].

A.2.1.1 Acoustic parameters of partitions to be evaluated [8]

A.2.1.1.1 Internal walls

The Sound Reduction Index (transmission loss) in the frequency range 100-3150 Hz, in 1/3-octave and octave bands, is defined as follows:

$$R = L_1 - L_2 + 10 \log_{10} \frac{S}{A} \qquad (1)$$

where:

L_1 = space-average sound pressure level in the source room, dB
L_2 = space-average sound pressure level in the receiving room, dB
S = area of the test specimen (m^2)
A = absorption in the receiving room (m^2).

A.2.1.1.2 Floor-ceiling assemblies

a) Sound Reduction Index (transmission loss) in the frequency range 100-3150 Hz, in 1/3-octave and octave bands, is defined as for walls, by Eq. (1).

b) Normalized Impact Sound Level in the frequency range 100-3150 Hz, in octave bands (or in 1/3-octave bands corrected to octave band levels by the addition of 5 dB) is defined as follows:

$$L_n = L - 10 \log \frac{A_o}{A} \qquad (2)$$

where:

L = space-average sound pressure level produced by the ISO standard tapping machine in the receiving room,
A = measured absorption in the receiving room (m^2)
A_o = reference absorption = 10 m^2.

A.2.1.1.3 External walls

The current ISO recommendation does not deal with the evaluation of the exernal walls; the revision of the standard, currently being balloted, does.

A.2.1.2 Assessment criteria for acoustical performance of partitions [*9*]

A.2.1.2.1 Airborne Sound Insulation

The transmission loss, presented in the form of a curve as a function of frequency, according to Eq. (1), is evaluated by comparison with the reference curve shown in Fig. A.1a, in order to determine the airborne sound insulation index, Ia. The method for comparing the transmission loss curve of the partition with the reference curve is as follows: the reference curve is shifted vertically in steps of 1 dB towards the measuring curve until the most severe of the following conditions is satisfied:

a) the mean unfavorable deviation, computed by dividing the sum of the unfavorable deviations by the total number of measuring frequencies, is greater than 1 dB but not more than 2 dB. This condition* for the curve can be expressed as follows:

$$1 \text{ dB} < \frac{\Sigma\delta i}{16} \leq 2 \text{ dB} \qquad (\text{ 1/3 octave bands}) \qquad (3a)$$

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*It should be noted that this rule does not lead to unambiguous ratings for TL curves that show unfavorable deviations at only a few frequencies. Several positions for the shifted curve can lead to values of ($\Sigma\delta i/16$) between 1 and 2 dB. The uncertainty in the value of the rating may be as much as 8 dB.

or $$1 \text{ dB} < \frac{\Sigma\delta i}{5} \leq 2 \text{ dB} \qquad \text{(for octave bands)} \qquad (3b)$$

b) the mean unfavorable deviation is less than 2 dB and the maximum unfavorable deviation at any frequency does not exceed 8 dB for measurements in 1/3 octave bands, or 5 dB for measurements in octave bands. This condition (which will be dropped in the next revision of the standards) can be expressed as follows:

$$\delta_{max} \leq 8 \text{ dB} \qquad \text{(for 1/3-OB)} \qquad (4a)$$

$$\delta_{max} \leq 5 \text{ dB} \qquad \text{(for OB)} \qquad (4b)$$

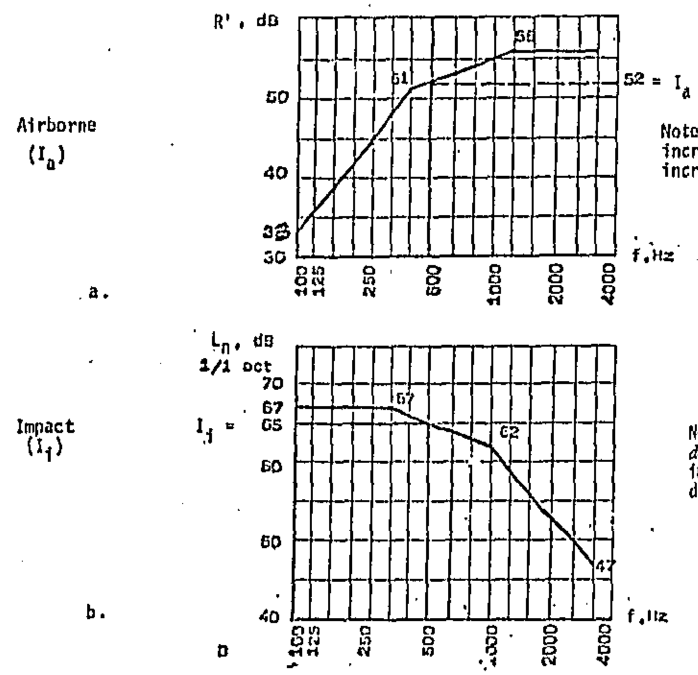
The airborne sound insulation index, Ia, of the partition is defined to be the value of the shifted reference curve at 500 Hz.

A.2.1.2.2 Impact sound insulation

The normalized impact sound level, calculated according to formula (2) and expressed in a curve as a function of frequency in octave bands (or 1/3-octave bands corrected to octave band level by adding 5 dB) is evaluated by comparison with the reference curve shown in Fig. A.1b, in order to determine the impact sound index, I_i.

The method of comparing the curve of the normalized impact sound level with the reference curve is similar to the method described above for airborne sound insulation.

The normalized impact sound index, I_i, is defined to be the value of the shifted reference curve at 500 Hz.



Note: Value of I_a increases as TL increases.

Note: Value of I_i *decreases* as impact noise level decreases.

FIG. A.1. REFERENCE CURVES FOR AIRBORNE (I_a) AND IMPACT (I_i) SOUND INSULATION USED IN THE ISO RATING METHOD.

A.2.1.3 Recommended acoustical properties of partitions

ISO recommendation R-717-1968 describes only a method of evaluating the transmission loss and normalized impact sound level with single-number ratings. It does not specify requirements for acoustical performance of partitions in dwellings.

A.2.2 United States

There are no USA Standards which prescribe, for the whole country, either assessment criteria or uniform requirements for the acoustical properties of partitions.

For evaluation of the acoustical properties, the test methods of A.S.T.M. are used [*4,5,6,7*], and required acoustical properties of partitions are given in recommendations and regulations issued by certain Federal and State Administrations for certain limited applications (such as Federally-insured housing).

A.2.2.1 Acoustical parameters of building partitions to be evaluated [*4,5*]

A.2.2.1.1 Interior walls

The acoustical properties of interior walls are determined in the laboratory according to Ref. 4 by measurement of the transmission loss TL, defined by a formula similar to Eq. (1), in the range 125-4000 Hz in 1/3-octave bands. In the field, transmission loss is measured according to Ref. 5, which includes a mandatory test to demonstrate the absence of significant flanking transmission.

A.2.2.1.2 Floor-ceiling assemblies between dwellings

a) The transmission loss is determined as for walls, according to Ref. 4 in the laboratory and to Ref. 5 in buildings.

b) The normalized impact sound level underneath the floor is determined according to Ref. 7; it is designated with the symbol L_N, and is calculated according to Eq. (2).

The normalized impact sound level L_N is determined in the range 125-4000 Hz in 1/3-octave bands, and is *not* corrected to correspond to octave-band levels, as in the ISO standard R-717.

A.2.2.2 Assessment criteria for acoustical performance of partitions

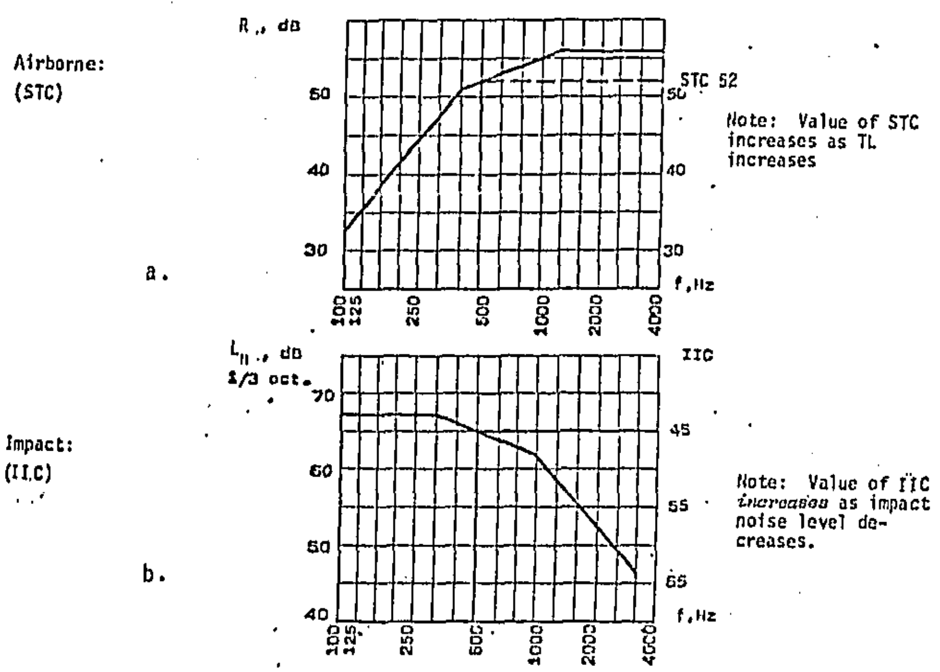
A.2.2.2.1 Airborne sound insulation

Assessment criteria for the transmission loss of a partition are given in Ref. 6. On the basis of the measured transmission loss (TL) of a partition, presented in the form of a graph as a function of frequency, the sound transmission class, STC, is defined by comparison of the measured TL curve with a set of tabulated reference curves of the shape shown in Fig. A.2a. The set contains curves which differ one from another by 1 dB. From the set of reference curves the curve is selected that corresponds to the TL of the partition according to the following rules:

a) the sum of the unfavorable deviations of partition TL values from the reference curve does not exceed 32 dB.

b) the maximum unfavorable deviation does not exceed 8 dB. The STC for the test partition is defined to be the 500 Hz value of the selected reference curve.

The method for determination of the STC is similar to that given in ISO Recommendation R-717 for determining the index I_a. The main difference is in the range of frequencies considered, which in ISO/R-717 comprises 100-3150 Hz, and in ASTM comprises 125-4000 Hz. Other slight differences appear in the method for comparison of the measured transmission loss curve with the reference curve; e.g., the ASTM method



Note: Value of STC increases as TL increases

Note: Value of IIC *increases* as impact noise level decreases.

FIG. A.2. REFERENCE CURVES FOR AIRBORNE (STC) AND IMPACT (IIC) NOISE USED IN NORTH AMERICA.

does not risk the ambiguity in the value of the rating entailed by the use of Eq. (3), as in the ISO method.

A.2.2.2.2 Impact sound insulation

The impact insulation class IIC is based on comparison of the measured normalized impact sound level L_N, presented in the form of a graph as a function of frequency, with a set of curves as shown in Fig. A.2b.

The set contains curves which differ by 1 dB. The method for comparison of the measured curve of L_N with the reference curves is similar to the method used by ASTM for airborne sound. The impact insulation class IIC is numerically equal to 110 dB minus the ordinate of the selected reference curve at 500 Hz.

A.2.2.3 Required sound insulating properties of partitions

Requirements for the sound insulating properties of building partitions are given in the Recommendations and Regulations of several City, State and Federal authorities.

Recommended acoustical parameters, given below as illustrative examples, are taken from the following documents:

a) Minimum Property Standards for Multifamily Housing. U.S. Dept. of Housing and Urban Development, FHA, Washington, D.C. [*26*].

b) A Guide to Airborne, Impact, and Structure Borne Noise Control in Multifamily Dwellings - Report No. FT/TS 24, January 1968, U.S. Department of Housing and Urban Development, Washington, D.C. [*27*].

c) Uniform Building Code - UBC [*28*].

The majority of these recommendations specify requirements for the sound insulating properties of internal partitions that depend on the noisiness of the neighborhood. The requirements for sound insulating properties of partitions separating dwellings also differ according to the types of rooms adjoining the partition (bedrooms, kitchens, bathrooms, etc.).

A.2.2.3.1 FHA Minimum Property Standards

The requirements for acoustical performance of buildings in FHA's Minimum Property Standards comprise airborne and impact sound insulation: the airborne insulation requirements are mandatory, the impact insulation performance is still only recommended at the present time. The acoustical minimum property standards take into account the amount of background noise likely to exist at the building site, because the effect of such background noise is to mask intrusive sounds from the neighbors. Thus, minimum property standards are prescribed in two categories, one for high, the other for low, background noise levels.

The actual levels of background noise intended by the terms "high" and "low" are not stated. Instead, the standards adopt the concept of land-use intensity, established for site planning at FHA, as an index of potential background noise. This determination is made by the local FHA field office for each specific housing project. (The determination of land-use intensity is complicated and not susceptible to easy summarization; no attempt is made to explain it further here). A land-use intensity of 6.0 or higher is assumed to have traffic and density characteristics that lead to high background noise levels. (Unofficially, the high and low background noise levels have been said to correspond to 35 dBA and 25 dB, respectively, indoors at night).

The rating for airborne sound insulation is the Sound Transmission Class (STC) [*6*]; for impact noise insulation, it is the Impact Noise Rating (INR) [*25*]. (See the comments following Ref. 25 and Ref. 27 in the list of references.)

TABLE A.2 FLOORS AND CEILINGS: SOUND TRANSMISSION LIMITATIONS.

Location of Floor	Airborne Sound Transmission Class (STC)		Impact Noise Rating (INR)	
	Low Background Noise	High Background Noise	Low Background Noise	High Background Noise
Floors Separating Living Units	50	45	0	-2
Corridor Floors above Living Units	50	50	+5	+2
Living Unit Floors above Public Space or Service Areas	50(6)	45(6)	-5	-8
Public Space or Service Areas above Living Units	55(6)	50(6)	+5	+5
Service Areas on same Floor as Living Units	NA	NA		

A.2.2.3.2 Guide to Airborne, impact, and structureborne noise control in multifamily dwellings [27]

This guidebook was prepared for the Federal Housing Administration (FHA) of the U.S. Department of Housing and Urban Development (HUD) by staff members of the U.S. National Bureau of Standards. It is a very complete and useful textbook for the provision of sound isolation in dwellings, and has had wide circulation. (It has just recently been reprinted, with a minor change in title). It is intended as a guide for FHA/HUD field staff in judging the adequacy of building sound insulation (for example, in the inspection of building drawings). It contains a large collection of typical wall and floor constructions, with corresponding acoustical performance, as well as a catalog of do's and don't's to serve as guidance for designing and executing details of the building construction.

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The airborne and impact sound insulation recommendations given in Chapter 10 of Ref. 27, and described below, do not represent official policy of FHA/HUD. It will be noted that they are considerably more strict than the FHA Minimum Property Standards for sound insulation.

The requirements for acoustical insulating properties of internal partitions are, in a general way, divided into three grades, according to the noisiness of housing area.

Grade I is used for suburban areas which can be considered as "quiet", with outdoor A-weighted noise levels during the night of 35 to 40 dB or lower weighting network. Indoor noise is about NC 20-25.

Grade II is the most improtant, and is used for urban residential areas and suburban areas with "average" noise level. The outdoor A-weighted noise level during the night can be 40 to 45 dB; acceptable indoor noise is NC 25-30.

Grade III corresponds to minimum requirements, and is used for urban residential areas and other "noisy" locations. The outdoor A-weighted noise during the night is about 55 dB or higher, and the indoor noise is up to NC 35.

KEY CRITERIA FOR AIRBORNE AND IMPACT SOUND INSULATION BETWEEN DWELLING UNITS

	Grade I	Grade II	Grade III
Walls	STC 55	STC 52	STC 48
Floor-Ceiling Assemblies	STC 55 IIC 55	STC 52 IIC 52	STC 48 IIC 48

Specific recommendations for sound insulation are given in unbelievable detail, depending on the kinds of spaces separated by the partition in question, though the fact that the stated requirements pertain to individual structural elements is not made clear. No requirements are placed on sound isolation between dwellings.

These super-detailed requirements are unmatched in the technical literature for unwarranted pretentions to significance and scientifically unfounded fine distinctions of acoustical quality.

CRITERIA FOR AIRBORNE SOUND INSULATION OF WALLS BETWEEN DWELLING UNITS

Partition Function Between Dwellings

Apt. A	Apt. B	Grade I STC	Grade II STC	Grade III STC
Bedroom	to Bedroom	55	52	48
Living room	to Bedroom	57	54	50
Kitchen	to Bedroom	58	55	52
Bathroom	to Bedroom	59	56	52
Corridor	to Bedroom	55	52	48
Living room	to Living room	55	52	48
Kitchen	to Living room	55	52	48
Bathroom	to Living room	57	54	50
Corridor	to Living room	55	52	48
Kitchen	to Kitchen	52	50	46
Bathroom	to Kitchen	55	52	48
Corridor	to Kitchen	55	52	48
Bathroom	to Bathroom	52	50	46
Corridor	to Bathroom	50	48	46

CRITERIA FOR AIRBORNE AND IMPACT SOUND INSULATION OF FLOOR-CEILING ASSEMBLIES BETWEEN DWELLING UNITS

Partition Function Between Dwellings

	Grade I		Grade II		Grade III	
	STC	IIC	STC	IIC	STC	IIC
Bedroom above Bedroom	55	55	52	52	48	48
Living room above Bedroom	57	60	54	57	50	53
Kitchen above Bedroom	58	65	55	62	52	58
Family room above Bedroom	60	65	56	62	52	58
Corridor above Bedroom	55	65	52	62	48	58
Bedroom above Living room	57	55	54	52	50	48
Living room above Living room	55	55	52	52	48	48
Kitchen above Living room	55	60	52	57	48	53
Family room above Living room	58	62	54	60	52	56
Corridor above Living room	55	60	52	57	48	53
Bedroom above Kitchen	58	52	55	50	52	46
Living room above Kitchen	55	55	52	52	48	48
Kitchen above Kitchen	52	55	50	52	46	48
Bathroom above Kitchen	55	55	52	52	48	48
Family room above Kitchen	55	60	52	58	48	54
Corridor above Kitchen	50	55	48	52	46	48
Bedroom above Family room	60	50	56	48	52	46
Living room above Family room	58	52	54	50	52	48
Kitchen above Family room	55	55	52	52	48	50
Bathroom above Bathroom	52	52	50	50	48	48
Corridor above Corridor	50	50	48	48	46	46

CRITERIA FOR AIRBORNE SOUND INSULATION WITHIN A DWELLING UNIT

Partition Function Between Rooms

	Grade I STC	Grade II STC	Grade III STC
Bedroom to Bedroom	48	44	40
Living room to Living room	50	46	42
Bathroom to Bedroom	52	48	45
Kitchen to Bedroom	52	48	45
Bathroom to Living room	52	48	45

A.2.2.3.2 *Sound insulation requirements for internal partitions as given in the Uniform Building Code - UBC*

The recommended airborne sound insulation of wall partitions between dwellings should provide STC 45 to 50 (derived from field measurements).

The recommended airborne sound insulation of floor-ceiling assemblies between dwellings should provide STC 45 to 50 and impact insulation class IIC 50.

The entrance doors leading from the inner corridors to dwellings should provide STC 30.

A.2.3 West Germany (German Federal Republic)

A.2.3.1 Acoustical parameters of partition to be evaluated

According to the West German Standard [*10*], the following acoustical parameters should be evaluated:

A.2.3.1.1 *Internal walls*

The transmission loss determined by laboratory measurement R (or by field measurement, R') as expressed by Eq. (1), in the range 100 to 3150 Hz and 1/3 octave bands.

A.2.3.1.2 *Floors*

a) The transmission loss is determined by laboratory measurement R (or by field measurement, R') expressed by Eq. (1); and

b) The normalized impact sound level is determined by laboratory measurement L_N (or by field measurement, L_N') in the range 100 to 3150 Hz in 1/3 octave bands, and is corrected to octave band levels by the addition of 5 dB.

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A.2.3.2 Assessment criteria for acoustical performance of partitions

A.2.3.2.1 Airborne sound insulation

The transmission loss R (or R'), shown in the form of a curve as a function of frequency, is evaluated by comparison with the reference curves shown in Fig.A.2a in order to determine the airborne sound insulation index, LSM (Luftschall Schutz Mass). This index LSM is different from the index I_a defined by ISO/R-717 and the U.S. index, STC. Approximately, I_a = STC = LSM + 52.

Reference curve I of Fig.A.2a serves for evaluation of the sound insulation of a partition, R'_w determined by measurements *in the building* or in measurement laboratories with flanking transmission. It is identical with the ISO reference curve for airborne sound insulation.

Reference curve II of Fig.A.2a serves for evaluation of sound insulation R_w of partitions, determined by laboratory measurements without flanking transmission.

Curves I and II differ by 2 dB. The sound insulation indices, LSM, measured in a laboratory and in a building, are equal when the effect of flanking transmission does not exceed 2 dB.

The method for comparison of the transmission loss curve of the partition with the reference curve is as follows: the reference curve is shifted in steps of 1 dB towards the measured curve R until the most severe of the following conditions is satisfied:

a) the mean unfavorable deviation of the partition insulation curve from the shifted reference curve, computed as the sum of the unfavorable deviations in the bands from 125 to 2500 Hz, increased by 1/2 of the sum of the unfavorable deviations at 100 and 3200 Hz and divided by 15, will be within these limits:

$$1\ \text{dB} < \delta_{mean} < 2\ \text{dB}$$

This condition can be expressed as follows:

$$1\ \text{dB} < \delta_{mean} = \frac{0.5(\delta_{100} + \delta_{3200}) + \overset{i=2500}{\underset{i=125}{}}\ \delta_i}{15} \leq 2\ \text{dB} \quad (5)$$

b) the mean unfavorable deviation in any 1/3 octave band does not exceed 8 dB. Both conditions must be satisfied at the same time.

The sound insulation index of a partition, whose transmission loss, according to the above conditions, corresponds to the reference curve of Fig.A.3a, is LSM = 0.

The sound insulation indices of a partition whose transmission loss corresponds to the reference curve shifted by ± a dB is:

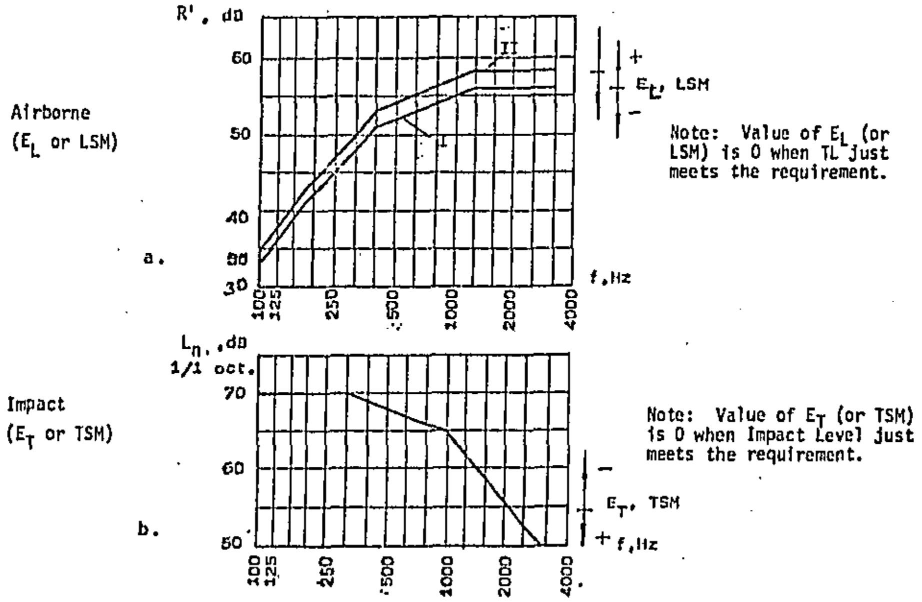
$$\text{LSM} = \pm\ a\ \text{dB}$$

A positive shift (indicated with plus sign) means shifting towards an *increase* in partition insulation, i.e., upwards in the diagram.

A.2.3.2.2 Impact sound insulation

The normalized impact sound level, defined as the impact level in 1/3 octave bands (corrected to octave bands by the addition of 5 dB) is evaluated by comparison with the reference curve of Fig.A.3b, in order to determine the index, TSM (Trittschall Schutz Mass).

The method of comparing the curve L_N, normalized impact sound level with the reference curve is similar to the above described method for the insulation of a partition with respect to air borne sound.



Note: Value of E_L (or LSM) is 0 when TL just meets the requirement.

Note: Value of E_T (or TSM) is 0 when Impact Level just meets the requirement.

FIG. A.3. REFERENCE CURVES FOR AIRBORNE (E_L) AND IMPACT (E_T) SOUND INSULATION USED IN THE RATINGS OF CMEA, POLAND, CZECHOSLOVAKIA, AND EAST AND WEST GERMANY (LSM AND TSM).

The impact sound index, TSM, computed for a floor construction with a curve L_N corresponding to the reference curve of Fig. A.3b, is TSM = 0.

The index computed for a curve L_N corresponding to the measured curve shifted in relation to the reference of curve Fig.A.3b by ± a dB is:

$$TSM = \pm a \text{ dB}$$

A positive shift (indicated with plus sign) means shifting towards a *decrease* of impact sound level (i.e., downwards in the diagram) which signifies an improvement of the impact insulation.

Again, the index TSM is not the same as the ISO index, I_1, nor the U.S. index, IIC. Approximately, $I_1 = 115 - IIC = 68 - TSM$.

A.2.3.3 Required acoustical properties of partitions

The West German Standard specifies the following requirements for the acoustical properties of interior partitions in residential buildings.

		Minimum Requirement		Better
walls separating apartments	LMS =	0	to	+3 dB
floors separating apartments or separating apartments from auxiliary rooms	LMS =	0	to	+3 dB
	TSM =	+3	to	+13 dB

Note: The index TSM for floors of kitchens, bathrooms and W.C. compartments refers to "diagonal" impact sound penetrating into living-rooms and bedrooms.

Note: In the following case, the required TSM index concerns impact sound penetration from one apartment to another apartment situated on the same level:

floors in duplexes LSM - not defined
TSM = +3 dB

Note. All specified values of TSM indices concern newly built floor-ceiling assemblies. The required TSM indices are 3 dB lower after a two-year period of use of the floors.

The DIN 4109 standard does not specify any requirement for the acoustical properties of partitions within a dwelling, nor for external walls and windows in residential buildings.

A.2.4 Sweden

A.2.4.1 Acoustical parameters of partition to be evaluated

A.2.4.1.1 Interior walls [12,13]

The transmission loss determined by laboratory measurement, R, as expressed in Eq. (1), in 1/3-octave bands in the range from 100 to 3150 Hz, according to the ISO Recommendation, R 140.

A.2.4.1.2 Floors [12,13]

a) The laboratory transmission loss, R, as for walls; and

b) The normalized ($A_o = 10\ m^2$) impact sound level, L_N, determined by laboratory measurement in 1/3-octave bands in the range from 100 to 3150 Hz, according to ISO Recommendation R 140, except that there is no correction to octave band levels, by the addition of 5 decibels.

A.2.4.2 Assessment criteria for acoustical performance of partitions

A.2.4.2.1 Airborne sound insulation [12,13]

The measured laboratory curve of transmission loss is compared with the ISO airborne sound criterion curve to determine the airborne sound insulation index, I_a, by a method similar to the ISO procedure. The fitting rules, however, are those of ASTM, rather than ISO, that is the sum of the unfavorable deviations must not exceed 32 dB and the maximum unfavorable deviation must not exceed 8 dB.

A.2.4.2.2 Impact sound insulation

The measured curve of normalized impact noise (1/3-octave band) levels is fitted, according to the ASTM rules, to a criterion curve that lies 5 decibels lower than the ISO criterion curve for impact noise. When the proper fitting has been achieved, the impact noise is taken as the value of the shifted criterion curve at 500 Hz, with 5 dB added. Thus, the Swedish impact noise index is the same as that of ISO, apart from the slight differences that may arise because of the slightly different fitting rules.

A.2.4.3 Requirements for acoustical properties of partitions [*11, 12*]

The Swedish code specifies the following acoustical properties for partitions in apartment houses:

	I_a Min.*		I_i Max.*
	Horiz.	Vert.	
Between a dwelling room outside the apartment and a room inside the apartment:	52	53	63
Between a storeroom outside the apartment and a room inside the apartment:	48	49	68
Between a staircase or corridor and a dwelling room inside the apartment:	52**	53**	68

---

*The "8 dB maximum deviation" rule is not applied in the 100 and 125 Hz bands.

**It is taken for granted that the sound transmitted through the doors will govern these values; such doors should have an airborne sound insulation index of at least 30 dB.

Requirements are also given for row-houses, hotels, hospitals, schools and office buildings.

No quantitative requirements are given for exterior walls, but it is recommended that special windows and doors be used in neighborhoods with heavy traffic noise.

A.2.5 Switzerland

A.2.5.1 Acoustical parameters of partition to be evaluated

A.2.5.1.1 Interior walls

The transmission loss determined by laboratory measurement, R, as expressed in Eq. (1), in 1/3-octave bands from 100 to 3150 Hz, according to ISO R-140.

A.2.5.1.2 Floors

The transmission loss, as for walls, and the normalized (A_o = 10 m^2) impact sound level, L_N, in 1/3-octave bands in the range from 100 to 3150 Hz, corrected (by the addition of 5 dB) to octave band levels.

A.2.5.2 Assessment criteria for acoustical performance of partitions

A.2.5.2.1 Airborne sound insulation

The ISO airborne sound insulation index, I_a, is used.

A.2.5.2.2 Impact sound insulation

The ISO impact sound insulation index, I_i, is used.

A.2.5.3 Requirements for acoustical properties of partitions [*17*]

The Swiss code specifies the following acoustical properties for partitions in apartment houses:

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	I_a		I_i	
	Min.	Recomm.	Min.	Recomm.
Party walls between apartments, staircase walls next to living and sleeping rooms and floor-ceilings in multi-story buildings	50	55	65	55
Other staircase walls	45	50		
Corridors	-	-	65	55
Walls and floors between apartments and shops, restaurants and offices	60	65	50	45
Apartment entry doors:				
To staircase	20	25	-	-
To exterior	-	25	-	-
Windows and French doors	20	30	-	-

Row houses, terrace houses and condominiums should satisfy the recommended insulation values: in a current code revision [*18*], the minimum requirements are permitted in condominium reconstruction costing less than 275 Fr/m^3.

The acoustical properties specified above refer to horizontal, vertical and diagonal directions of propagation. The building must satisfy the stated requirements even two years after completion; it is recognized that the sound insulation may change by 1 to 3 dB in the first two years.

Requirements are also given for maxiumu permissible noise levels due to equipment in the dwelling and penetrating from outdoors.

A.2.6 Denmark [*19-21*]

A.2.6.1 Acoustical parameters of partitions to be evaluated

A.2.6.1.1 Interior walls

The primary requirement is given in terms of normalized level difference, D_{nt}, measured in the finished building according to ISO, but with all band levels normalized to 0.5 sec reverberation time at 500 Hz.* Measurements are made in 1/3-octave bands in the range from 100 to 3150 Hz.

In addition, for planning and design purposes, requirements are given for the laboratory measured transmission loss of specific building elements, according to the ISO procedure, in 1/3-octave bands from 100 to 3150 Hz.

A.2.6.1.2 Floors

Normalized level difference in the finished building is the primary measure for airborne sound, but laboratory transmission loss is used for planning, just as for walls.

Impact noise level, normalized to 0.5 reverberation time at 500 Hz,* is used, measured in accordance with the ISO procedure.

A.2.6.2 Assessment criteria for acoustical performance of partitions

A.2.6.2.1 Airborne sound insulation

No index of sound insulation is explicitly used. Instead, the performance is rated in terms of both the arithmetical average of the sixteen 1/3-octave band values of D_{nt} (or R) and also sixteen tabulated values of minimum acceptable D_{nt} (or R). These tabulated values, however, correspond in each case to the 1/3-octave-band levels that define an ISO airborne sound insulation index, I_a. Deviations toward lower values are allowed, provided these deviations do not exceed 1 dB, averaged over the whole frequency range (ISO permits 2 dB average unfavorable deviation). In effect, therefore, the airborne sound insulation requirements are as

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*I.e., *all* measured levels are corrected by 10 log $0.5/T_{500}$ where T_{500} is the receiving room reverberation time at 500 Hz.

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though they were expressed in terms of I_a, but with 1 dB stricter tolerance in assigning the rating.

A.2.6.2.2 Impact sound insulation

No index of impact sound insulation is used. Instead, tabulated values of maximum acceptable impact noise are given for the sixteen frequency bands between 100 and 3150 Hz. The average unfavorable deviation may not exceed 1 dB.

A.2.6.3 Requirements for acoustical properties of partitions [20]

Although the Danish code specifies the requirements for normalized level difference and transmission loss by tabulating the minimum acceptable values for each 1/3-octave band, since these tabulated values correspond in each case to one of the indices, I_a, it is convenient to present the code requirements here in terms of I_a, shifted by 1 dB in order to account for the stricter tolerance in fitting the measured data to the required values. (In other words, if the tabulated values of transmission loss in the Danish code correspond to the curve for $I_a = 49$, we report the requirement as $I_a = 50$.)

For impact noise insulation, the tabulated values of maximum allowable impact noise level are quite unlike the ISO criterion curve for impact noise, falling off much more steeply at high frequencies. Nevertheless, it is convenient to report the Danish impact noise requirement in terms of the value of I_i that would be assigned by ISO rules to an impact noise curve one decibel higher than the impact noise levels tabulated in the Danish code. In addition, the tabulated values themselves are given here.

A.2.6.3.1 Airborne sound insulation

Required minimum acceptable values are given for both the average value of normalized noise reduction, D_{nt}, over the sixteen measurements bands, as well as for the value of D_{nt} in each band, as follows:

	Average D_{nt}	Equivalent I_a (see §6.3)
Apartment buildings	49 dB	51 dB
Terrace and semi-detached houses	52	54

In addition, required values of transmission loss for party walls are also given as follows:

	Average TL	Equivalent I_a
Apartments	50 dB	53 dB
Terrace and semi-detached houses	53	56

For apartment floor-ceiling structures, the average transmission loss must be 52 dB and the equivalent I_a must be 55 dB; the impact noise levels in 1/3-octave bands may not exceed the following tabulated values by more than 1 dB, averaged over all the bands, a requirement equivalent to an impact noise insulation index, I_1, of 58 dB (see Fig.A.4 and A.2.6.3 above):

Frequency (Hz) (Hz)	100	125	160	200	250	315	400	500
Impact Noise Level (dB)	65	65	65	65	63	61	59	57
Frequency (Hz)	630	800	1000	1250	1600	2000	2500	3150
Impact Noise Level (dB)	55	53	51	48	45	42	39	36

Note:

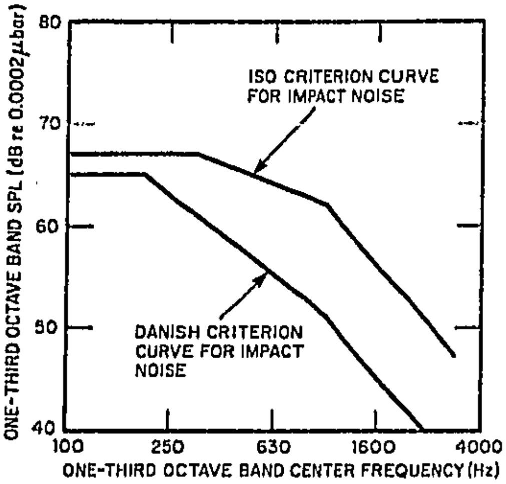

FIG. A.4. DANISH IMPACT NOISE REQUIREMENT, IN COMPARISON WITH THE ISO REFERENCE CURVE.

The Danish Housing Department intends to change the form of noise control regulations soon, to conform more nearly with the current Swedish approach. The new requirements are expected to be issued at the end of 1976 [*21*].

A.2.7 The Netherlands [*22,23*]*

A.2.7.1 Acoustical parameters of partitions to be evaluated [*22a*]

A.2.7.1.1 Interior walls

The normalized level difference, D_{nt}, is measured in octave bands in the range from 125 to 2000 Hz, and normalized to a receiving room reverberation time of 0.5 sec.**

A.2.7.1.2 Floors

The normalized level difference, D_{nt}, is used for airborne sound, as for floors; in addition, the normalized impact noise level is measured in octave bands in the range from 125 to 2000 Hz, and normalized to a receiving room reverberation time of 0.5 sec.**

A.2.7.2 Assessment criteria for acoustical performance of partitions [*22a*]

A.2.7.2.1 Airborne sound isolation

Although the requirements for basic measured data are less demanding in the Dutch code than in other countries (only five octave bands are considered), the criterion

---

*The Netherlands is only months away from adopting a new standard for noise control in dwellings [*22a*]; the information given here pertains mostly to the new version, but rerequirements for the old code [*22*] are also given in parentheses.

**In the old standard [*22*], the frequency range was from 250 to 2000 Hz, and the measured levels were normalized to $10m^2$ sound absorption in the receiving room.

ratings based on these data are rather complicated, both for airborne and impact sound insulation.

For airborne sound, the airborne noise isolation index, I_{1u}(not at all like the ISO airborne sound insulation index, I_a), is formed as follows:

For each of the five octave bands of interest, criterion values of normalized noise level difference are defined by the code:*

Frequency (Hz)	125	250	500	1000	2000
Criterion D_{nt}(dB)	35(-)	44(43)	51(50)	54(53)	55(54)

These criterion values are to be subtracted from the field-measured values of D_{nt} in the corresponding bands to yield a set of five values of "airborne noise isolation discrepancy", which may be either positive or negative. From these values of isolation discrepancy, three quantities are to be calculated:

a) The algebraic average, rounded to the nearest integer;

b) The algebraic average of the two (algebraically) smallest of the five discrepancies, increased by 2 and rounded to the nearest integer.

c) The algebraically smallest of the discrepancies, increased by 4 and rounded to the nearest integer.

The airborne noise isolation index, I_{1u}, is the smallest of these three results.

An example is given below for the calculation of I_{1u}.

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*The values in parentheses are the requirements of the old code [22].

EXAMPLE:

Frequency:	125	250	500	1000	2000	(Hz)
1. Octave-band level in source room, dB	99.4	99.8	101.1	99.9	99.3	
2. Octave-band level in receiving room, dB	67.2	60.7	51.3	43.2	40.0	
3. Reverberation time in receiving room, sec.	1.0	1.1	1.0	0.9	0.7	
4. 10 log (T/0.5)	+3.0	+3.4	+3.0	+2.6	+1.5	
5. Normalized level difference, D_{nt}, dB (= 1 - 2 + 4)	35.2	42.5	52.8	59.3	60.8	
6. Criterion values of D_{nt}, dB	35	44	51	54	55	
7. Isolation discrepancy, dB	+0.2	-1.5	+1.8	+5.3	+5.8	

From the five values of isolation discrepancy (line 7), calculate the required three quantities:

a) 1/5 (+0.2 = 1.5 + 1.8 + 5.3 + 5.8) = 2.32, rounded to +2

b) 1/2 (0.2 - 1.5) + 2 = +1.35, rounded to +1

c) -1.5 + 4 = + 2.5, rounded to + 2

The airborne noise isolation index I_{lu} is the smallest of these three numbers, that is, + 1 dB.

A.2.7.2.2 Impact sound isolation

For impact sound, a similar index is formed, based on criterion values of impact noise level defined in the code, as follows:*

Frequency (Hz)	125	250	500	1000	2000
Criterion value of impact noise level (dB)	70(-)	66(72)	66(70)	66(67)	70(58)

---

*Note that the shape of the curve defined by these requirements is quite different from that of ISO or the other countries studied here. The values in parentheses are the requirements of the old code [22].

The field measured values of normalized impact noise levels in octave bands are to be subtracted from the criterion values to yield five values of impact noise isolation discrepancy, which may be either positive or negative.

Again, three quantities are to be calculated from the five values of isolation discrepancy:

a) The algebraic average of the five values, rounded to the nearest integer

b) The algebraic average of the two (algebraically) smallest values, increased by 2 and rounded to the nearest integer

c) The algebraically smallest value, increased by 4 and rounded to the nearest integer.

The impact noise isolation index, I_{co}, is the smallest of these three results.

An example is given below to illustrate the calculation of I_{co}.

EXAMPLE:

Frequency:	125	250	500	1000	2000	(Hz)
1. Impact noise level, L	65.1	67.6	71.0	72.5	69.9	(dB)
2. Reverberation time, sec.	1.0	1.1	1.0	0.9	0.7	
3. 10 log (T/0.5)	+3.0	+3.4	+3.0	+2.6	+1.5	
4. Normalized impact noise level (≑ 1 - 3)	62.1	64.2	68.0	69.9	68.4	(dB)
5. Criterion values of impact noise level	70	66	66	66	70	(dB)
6. Impact isolation discrepancy	+7.9	+1.8	-2.0	-3.9	+1.6	

From the five values of isolation discrepancy (line 6), calculate the three required quantities:

a) 1/5 (+ 7.9 + 1.8 - 2.0 - 3.9 + 1.6) = + 1.08, rounded to + 1

b) 1/2 (- 2.0 - 3.9) + 2 = - 0.95, rounded to - 1

c) - 3.9 + 4 = +).1, rounded to 0

The impact noise isolation index, I_{co}, is the smallest of these three numbers, that is - 1.

A.2.7.3 Requirements for acoustical properties of partitions [23]*

A.2.7.3.1 Airborne sound insulation

The Dutch code specifies required values for the airborne noise isolation index, I_{lu}, as follows:

	SITUATION	I_{lu}
WALLS:	Dwellings, except single-family houses:	
	Party walls between dwellings, and corridor walls:	≥ 0
	If no bedroom or kitchen abuts the party wall:	$\geq - 3$
	Single-family houses:	
	Walls with bedroom or kitchen abutting:	≥ 0
	If no bedroom or kitchen abuts the wall:	$\geq - 3$
FLOORS:	Dwellings, except single-family houses:	
	Floor of private room (bedroom, kitchen or bath) above a non-private room (corridor or underpass):	≥ 0
	Floor of bedroom, kitchen or bath above common space (garage, storeroom, etc.):	≥ 0
	Floors separating dwellings:	≥ 0
	Floors separating common storage rooms from bedrooms underneath:	≥ 0
	Loggia or terrace floors with bedroom, kitchen or bath underneath:	≥ 0
	Single-family houses:	
	Floor of bedroom, kitchen or bath above non-private space (corridor or passage):	≥ 0

---

*The requirements for airborne and impact sound insulation indices given here are those of the current Dutch Uniform Building Code. In the new version of the noise control standard (Ref. 22a), the minimum requirement for the in- indices will be 0, but builders will be advised to use +5. The Uniform Building Code may or may not pick up this change.

A.2.7.3.2 Impact noise isolation

The following values are required for the impact noise isolation index, I_{co}:

Situation	I_{co}
Dwellings except single-family houses:	
Floors between dwellings:	≥ 0
Floors of common spaces (except for storage rooms), such as corridors, hall, landing, veranda, ramp, etc. above bedrooms:	≥ 0
Floors of non-private spaces (loggia, terrace or passage) above bedroom, kitchen or bath not entirely belonging to the same dwelling:	≥ 0

A.2.8 Great Britain

A.2.8.1 Acoustical parameters of partition to be evaluated

A.2.8.1.1 Walls

Transmission loss, R (or R') is used, determined according to Eq. (1).

A.2.8.1.2 Floors

Transmission loss R (or R') is used, determined according to Eq. (1); and normalized impact sound level, L_N, determined according to Eq. (2).

A.2.8.2 Assessment criteria and requirements

The curves that represent the assessment criteria for the acoustical properties of partitions in Great Britain are shown in Fig.A.5. They also, in effect, state the acoustical requirements of the code.

The curves differ in shape from the assessment curves used by the majority of countries discussed in this Appendix.

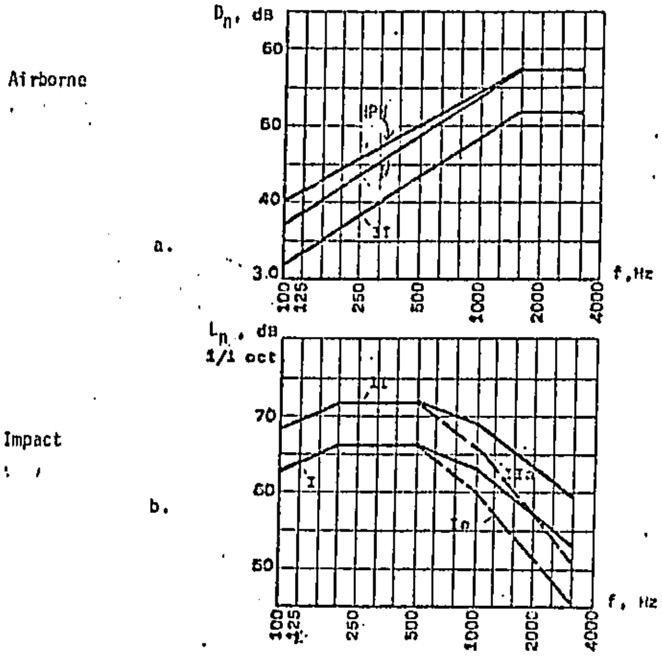

FIG. A.5. REFERENCE CURVES FOR ESTABLISHING AIRBORNE AND IMPACT SOUND INSULATION GRADES, USED IN ENGLAND; THERE IS NO SINGLE-NUMBER RATING INVOLVED.

A.2.8.2.1 Airborne sound insulation (transmission loss)

The airborne sound insulation criterion curves are shown in Fig. A.5a.

Curve II defines the minimum acceptable insulation for house party walls.

Curves I and II, together with the division into grades I and II, define the minimum acceptable insulation between dwellings in the same multi-family building.

A.2.8.2.2 Impact sound level

Curve I of Fig.A.5b shows the acceptable impact sound level for floors in building of grade I.

Curve II shows the acceptable impact sound level for floors in buildings of grade II.

Curves Ia and IIa refer to floors with carpet.

A.2.9 Belgium

A.2.9.1 Acoustical parameters of partition to be evaluated

A.2.9.1.1 Walls

a) The transmission loss R, determined by laboratory measurement according to Eq. (1) (indice d´affaiblissement acoustique d´une paroi);

b) Normalized level difference, D_N - (izolement acoustique normalisé), determined according to Eq. (5), with $A_o = 10\ m^2$.

A.2.9.1.2 Floors

a) The transmission loss R (or normalized level difference, D_N), as for walls,

b) Normalized impact sound level L_N (niveau du bruit de choc normalisé), determined according to Eq. (2), with $A_o = 10\ m^2$.

A.2.9.2 Assessment criteria and acoustical requirements

The curves that represent the assessment criteria as well as the acoustical requirements for partitions are shown in Fig. 6. These criteria and acoustical requirements concern both the transmission loss, R, as measured in the laboratory, and the normalized level difference, D_N, measured in the building, as well as the impact sound level, L_N (wherever measured).

The Belgian standard covers five grades of requirements for airborne sound insulation, R, and five for sound isolation, D. For each grade, the corresponding reference curves R, and D_N are defined by the code (Fig. A.6a). It should be noted that the difference between the required values of R and D_N is not constant, but increases from 0 for the lowest requirements to +3 dB for the highest requirements. It also should be noted that in the Belgian Standard the shape of the curve giving the required insulation for external partitions is not based on the spectrum of traffic noise; rather, it is the same as for the case of internal walls.

There are three grades for impact sound insulation. The *acoustical insulation rating category* is assigned according to the following rule: The mean unfavorable deviation of the measured partition curve from the reference curve must not exceed 1 dB in *each one* of the following ranges of frequencies:

100 - 315 Hz
400 - 1250 Hz
1000 - 3150 Hz

The required airborne sound insulation of partitions (R) and isolation between rooms (D_N) is as follows:

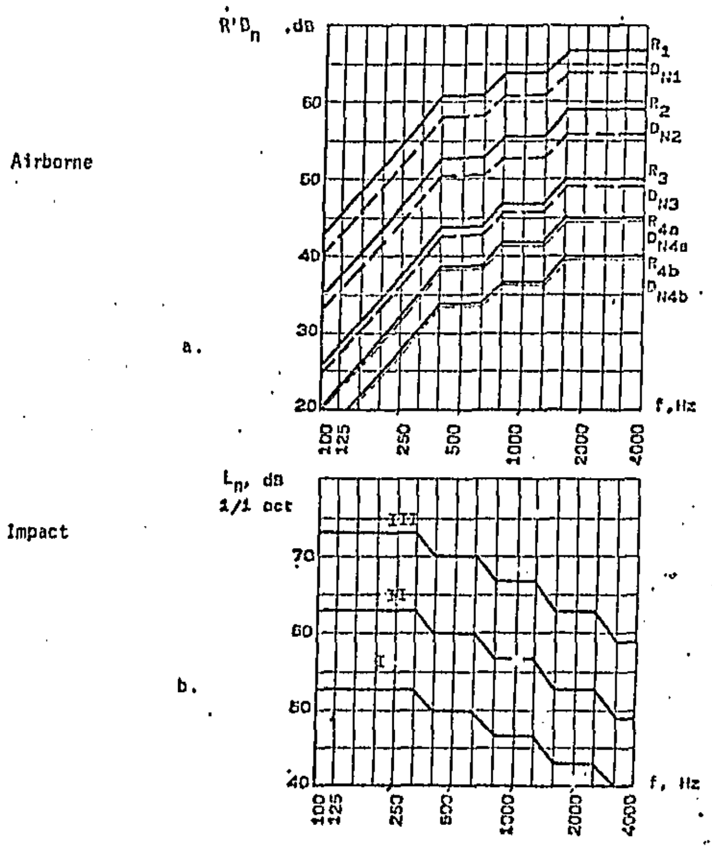

FIG. A.6. REFERENCE CURVES USED IN ESTABLISHING QUALITY CATEGORIES FOR AIRBORNE AND IMPACT SOUND INSULATION IN BELGIUM. THERE IS NO SINGLE-NUMBER RATING SYSTEM.

	Insulation Category	Isolation Category
partitions separating two apartments	R_2	D_{N2}
partitions separating staircase or elevators from the apartment, according to the type of room:		
bedroom	R_1	D_{N1}
living room	R_2	D_{N2}
nursery	R_3	D_{N3}
kitchen	R_3	D_{N3}
bathroom, W.C.	R_3	D_{N3}
partitions separating rooms in the apartment		
bedroom - bedroom	R_3	D_{N3}
bedroom - livingroom	R_2	D_{N2}
bedroom - nursery	R_2	D_{N2}
bedroom - kitchen	R_2	D_{N2}
livingroom - nursery	R_2	D_{N2}
livingroom - kitchen	R_3	D_{N3}
livingroom - bathroom	R_2	D_{N2}
kitchen - sanitary compartment	R_{4b}	D_{N4b}

Acceptable normalized impact sound levels L_N for floors are given according to the type of rooms situated in the vertical direction, as follows:

For Apartments		Upper Rooms				
		Bed-room	Living room, Dining room	Kitchen	Bath-room, W.C.	Children's Game-room
Lower Rooms	Bedroom	II	II	I	I	I
	Living room, dining room	III	II	II	I	I
	Kitchen	III	III	III	III	II
	Bathroom, W.C.	III	III	III	III	III
	Children's Game-room	III	III	III	III	III

A.2.10 France

Information on assessment criteria and requirements used in France for the acoustical properties of partitions in residential building was taken from publications of Centre Scientifique et Technique du Bâtiment, from a number of official decrees, and published technical discussions.

A.2.10.1 Acoustical parameters of partition to be evaluated

Acoustical assessment covers the following acoustical parameters of partitions:

A.2.10.1.1 Walls

a) The transmission loss, R (indice d'affaiblissement acoustique d'une paroi), expressed by Eq. (1), and determined in the frequency range 100-3150 Hz in 1/3 octave bands.

b) The normalized level difference, D_N, determined by laboratory measurements accoring to Eq. (5) in 1/3 octave bands from 100 to 3150 Hz; or by field measurements in octave bands in the range 125 to 4000 Hz, according to the following formula:

$$D_N = L_1 - L_2 + 10 \log \frac{T}{T_o} \qquad (10)$$

where:

T = reverberation time of the receiving room in seconds,

T_o = the reference reverberation time, taken as $T_o = 0{,}5$ second

The remaining symbols are as in Eq. (5).

A.2.10.1.2 Floors

a) The transmission loss, R, and the normalized level difference, D_N, as for walls.

b) The normalized impact sound level, L_N (niveau du bruit de choc normalisé)

for laboratory measurements - according to Eq. (2) in 1/3 octave bands, at 100 to 3150 Hz,

for field measurements, according to the following formula:

$$L_N = L - 10 \log \frac{T}{T_o} \qquad (11)$$

where:

T and T_o are as given in Eq. (10) and the remaining symbols are as given in Eq. (2), in octave bands at 125 to 4000 Hz.

A.2.10.2 Assessment criteria for acoustical properties of partitions

Airborne and impact sound insulation are determined in terms of calculated A-weighted sound levels, on the basis of the measured acoustical parameters of the partition as a function of frequency, according to A.2.10.1.

A.2.10.2.1 Transmission loss

The transmission loss is determined according to the following formula:

$$R_{wA} = L_{A1} - (L_{A2} - 10 \log \frac{S}{A}) \qquad (12)$$

where:

L_{A1} = calculated A-weighted sound level in the source room (dB)

$(L_{A2} - 10 \log \frac{S}{A})$ = calculated A-weighted sound level in the receiving room, based on octave band values of transmission loss, and taking account of the partition area and the absorption in the receiving room.

Note: In determining the transmission loss for *internal* walls in a building, the level, L_{A1}, in the source room is taken as constant at all frequencies (80 dB in each octave band). In determining the transmission loss for *external* walls in a building, the level L_{A1} in the source room is calculated from octave-band values of L_1 at various frequencies, as follows:

f (Hz)	125	250	500	1000	2000	4000
L_1 (dB)	71	72	66	65	63	47

A.2.10.2.2 Normalized level difference, D_N

The (A-weighted) normalized level difference is determined according to the following formula:

$$D_{NA} = L_{A1} - (L_{A2} - 10 \log \frac{T}{T_o}) \qquad (13)$$

where:

L_{A1} is as in Eq. (12); and

$(L_{A2} - 10 \log \frac{T}{T_o})$ = calculated A-weighted sound level in the receiving room, normalized to the reference reverberation time, $T_o = 0,5$ second.

The quantity, D_N, determined according to formula (13), is called in the technical French literature "isolement acoustique".

A.2.10.2.3 *Normalized impact sound level, L_N*

The A-weighted normalized impact sound level is calculated from the sound pressure level as a function of frequency according to formula (2) or (11).

A.2.10.3 Required acoustical properties of partitions

Requirements for the acoustical properties of partitions are stated in terms of:

a) normalized level difference, D_{NA}, according to:

$$D_{NA} = R_A - a + b \qquad (14)$$

where:

R_A = "A-weighted" transmission loss given in formula (12);

a = a positive number accounting for "A-weighted" flanking transmission; and

b = "A-weighted" normalization for reverberation time (T_o = 0.5 sec), as follows:

DRAFT

$$b = 10 \log \frac{0,161\ V}{10\ T_o}$$

The value of b may be found from the following table:

$\frac{V}{s}$(m)	1,2	1,6	2,0	2,6	3,2	4,0	5,0	6,3	8,0
b	-4	-3	-2	-1	0	+1	+2	+3	+4

b) A-weighted normalized impact sound level, L'_{NA}, in a building:

$$L'_{NA} = L_{NA} + a + b \qquad (15)$$

where:

L_{NA} = A-weighted impact sound level, determined according to §A.2.10.2.3;

a = positive number accounting for "A-weighted" flanking transmission; and

b = "A-weighted" normalization for reverberation time (T_o = 0.5 sec), as follows:

$$b = 10 \log \frac{0,161\ V}{10\ T_o}$$

The value of b may be found from the following table:

DRAFT

$V(m^3)$	16	20	25	32	40	50	63	80
b	+3	+2	+1	0	-1	-2	-3	-4

A.2.10.3.1 Regulations of June 1969

The French Regulations, compulsory since 14 June 1969 [*31,32*], include the following requirements for the acoustical properties of partitions in residential buildings.

	A-weighted Sound Level or Sound Level Difference
walls separating apartments	D_{NA} = 51 dB
floors separating apartments	D_{NA} = 51 dB
	L_{NA} = 70 dB
walls and floors separating apartments from shops	D_{NA} = 56 dB

A.2.10.3.2 "Acoustic Comfort Label" of February 1972

The more strict acoustical requirements for the attainment of the recently introduced "Acoustic Comfort Label" [*33,34*] are much more complicated and are described in the main text (3.4.2) of this report [*38,43*].

A.2.10.3.3 "Acotherme" windows [46]

The most recent change in France has been the introduction of the "Acotherme" Label for windows that fulfill special thermal and acoustical properties (improved insulation, up to 45 dB(A)). Various permutations of improvements in thermal and acoustical insulation in specially built windows are identified by differently colored labels.

The Council for Mutual Economic Aid (CMEA) and the Eastern Countries.

A.2.11 Standing Building Committee of Council for Mutual Economic Aid (CMEA) *[47,48]*

A.2.11.1 Acoustical parameters of partitions to be evaluated

A.2.11.1.1 Internal walls

The transmission loss, R_w, defined in the range from 100 to 3150 Hz in 1/3 octave bands is given by Eq. (1). If the source room is not adjacent to the receiving room (in a building), determination of the normalized level difference, D_N, is recommended, according to the following formula:

$$D_N = L_1 - L_2 + 10 \log \frac{A_o}{A} \qquad (5)$$

where:

L_1, L_2, A are as in Eq. (1), and

A_o = reference absorption area, taken as 10 m^2.

A.2.11.1.2 Floor-ceiling assemblies

a) The transmission loss (or normalized level difference) is defined as for walls, with the use of Eqs. (1) and (5).

b) The normalized impact sound level, determined for the range 100 to 3200 Hz in octave bands (or in 1/3 octave bands corrected to octave bands by the addition of 5 dB) is given by Eq. (2).

A.2.11.1.3 External walls

CMEA Recommendation RS 263-65 does not deal with external walls. Draft Recommendation RS 263-67 specifies acoustical properties for external walls with windows, but the formulation of this recommendation is rather general and no method for numerical evaluation is prescribed.

A.2.11.2 Assessment criteria for acoustical parameters of partitions

A.2.11.2.1 Airborne sound insulation

The transmission loss R (or R') or the normalized level difference, D_N, presented in the form of a curve as a function of frequency, is evaluated by the method given in §IIA.3.2.1 by comparison with reference curve I or II shown in Fig. 3a. Curve II is used for assessment of the laboratory transmission loss R, (or D_N) and Curve I for assessment of field transmission loss R'.

The condition to be met for comparison of the curve R (or R') is expressed by Eq. (5). After comparison of the curve R (or R') with the corresponding reference curve, the sound insulation index, E_L, is determined like the determination of the index LSM described in paragraph IIA.3.2.1.

A.2.11.2.2 Impact sound insulation

The normalized impact sound level L_N, presented in the form of a curve as a function of frequency, is evaluated by the method given in §IIA.3.2.2, by comparing the measured data with the reference curve of Fig. A.3b.

After comparing the measured curve of L_N with the reference curve, so as to meet the conditions of Eq. (5), the index E_T is determined like the index TSM.

A.2.11.3 Recommended acoustical properties of partitions

Recommendation RS 263-65 and Draft Recommendation RS 263-67 specify recommendations for the acoustical properties of internal partitions in residential buildings in terms of the indices E_L and E_T. Recommended acoustical properties for main partitions in residential buildings are as follows:

	RS 263-65	RS 263-67
walls between dwellings	$E_L = -1$ dB	$E_L = -1$ to $+2$ dB
floors between dwellings	$E_L = -1$ dB	$E_L = -1$ to $+20$ dB
	$E_T = 0$	$E_T = 0$ to $+10$ dB
floors between dwellings and auxiliary rooms situated above the dwellings in the building	$E_L = -1$ dB	$E_L = -1$ to $+20$ dB
	$E_T = 0$	$E_T - 0$ to $+10$ dB
floors of two-story buildings	E_L - not specified	
	$E_T = 0$	
walls between rooms within one dwelling	$E_L = -9$ dB	$E_L = -20$ to -9 dB

Note: Recommendations for the index E_T of floors between kitchens and bathrooms concern impact sound penetrating into rooms of the adjacent dwelling. Recommendations given in Draft RS 263-67 include both minimum values (lower indices) and preferred values (higher indices).

A.2.12 Poland

A.2.12.1 Acoustical parameters of partition to be evaluated

A.2.12.1.1 Internal walls

The transmission loss, R_W, concerns the acoustical properties of a partition determined without flanking transmission; the "approximate transmission loss", R'_W, concerns the acoustical properties of a partition in a building *with* flanking transmission. Values of transmission loss, R_W and R'_W, are determined in the frequency range 100 to 3150 Hz in octave bands according to Eq. (1).

A.2.12.1.2 Floor-ceiling assemblies

a) The transmission loss, R_W (or approximate transmission loss, R'_W) is determined in a manner similar to that for internal walls.

b) The normalized impact sound level under the floor (characterizing the transmission of impact sound), determined in 1/3 octave bands corrected to octave bands is defined as follows:

$$L_{ur} = L_u + 10 \log \frac{A_o}{A} + 10 \log n \qquad (7)$$

where:

n = a number dependent on the band width of the filters used; for octave band filters, n = 1, for 1/3 octave band filters, n = 3; the other symbols are as given in Eq. (2).

A.2.12.1.3 External walls and windows

The transmission loss, R_W, is defined as in the case of internal partitions in a diffuse field, according to Eq. (1), in the range 100 to 3150 Hz in 1/3 octave bands.

A.2.12.1.4 Entrance doors of flats

The transmission loss, R_W, is defined as in the case of internal partitions in a diffuse field, according to Eq. (1), in the range 100 to 3150 Hz in 1/3 octave bands.

A.2.12.2 Assessment criteria for acoustical parameters of partitions

A.2.12.2.1 Airborne sound insulation of internal partitions

The Polish Standard specifies criteria for evaluation of the transmission loss R_W and R'_W similar to those of CMEA Recommendation RS 263-65. The insulation of an internal partition is defined by the index E_L, computed as in the CMEA Recommendation (see § II.B.1.2 above).

A.2.12.2.2 Impact sound insulation

The Polish Standard specifies an assessment criterion for the normalized impact sound level, L_{ur}, as in the CMEA Recommendation RS 263-65 and the Draft RS 263-67. The impact sound insulation of a floor is characterized by the index E_T, computed as in the CMEA Recommendation (see § II.B.1.2 above).

A.2.12.2.3 Airborne sound insulation of external walls and windows

Assessment criteria for the transmission loss of *external* walls and windows in residential buildings were developed by the Research Institute, Department of Acoustics, in Warsaw. These criteria were the first in the world to be used in a national standard.

The transmission loss, presented in the form of a curve as a function of frequency, is evaluated by comparison with the reference curve of Fig. 7a in order to define the index ZE_L. The reference curve was developed by *considering the spectrum of traffic noise* and the *sound absorption of typical furnished apartments*, as a function of frequency.

The method for comparison of the transmission loss curve of an external wall or window with the reference curve is like the case of internal partitions, i.e., the method given in paragraph II.A.3.2.1.

The airborne sound insulation index for an external wall whose curve R_w exactly corresponds to the reference curve of Fig. 7a is:

$$ZE_L = 0 \text{ dB}$$

The index determined on the basis of a measured curve R_w, shifted in relation to the curve of Fig. 7a by ± a dB, is:

$$ZE_L = \pm a \text{ dB}$$

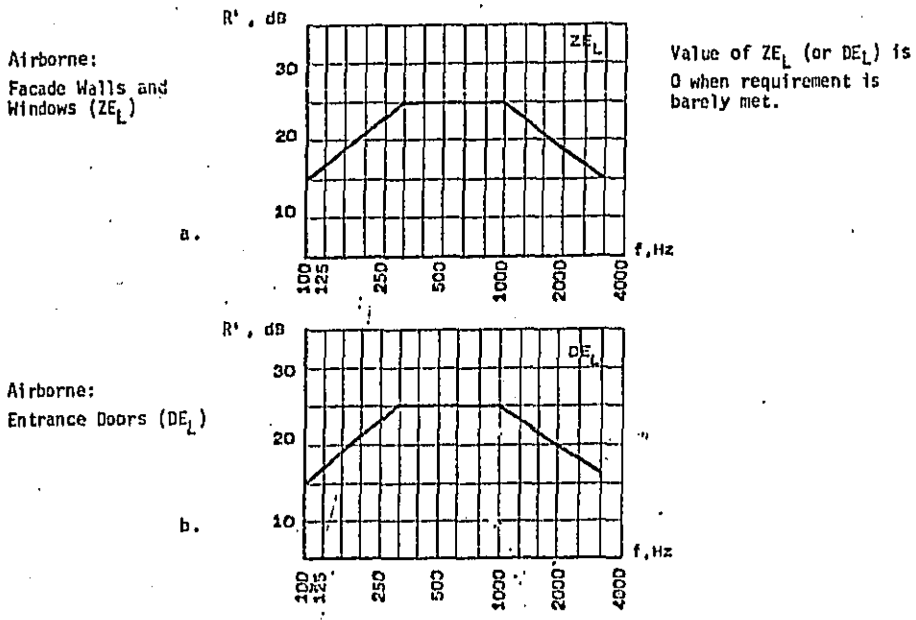

FIG. A.7. REFERENCE CURVES FOR AIRBORNE SOUND INSULATION RATING FOR FACADE WALLS AND WINDOWS (ZE_L) AND ENTRANCE DOORS (DE_L) IN POLAND.

A positive (indicated by a plus sign) means shifting towards an increase of the transmission loss of the partition, i.e., upwards in the diagram.

The Polish Standard specified an approximate relation between the index ZE_L of the window and the traffic noise level penetrating through the window, as follows:

$$L_{1A} - L_{2A} = 20 + ZE_L - 10 \log \frac{S}{A} \text{ dB} \qquad (8)$$

where:

L_{1A} = A-weighted sound level in dB outside the building at the window,

L_{2A} = A-weighted sound level in dB of traffic noise penetrating through the window into the room,

S = area of the window, in m^2,

A = acoustic absorption of the room, m^2, averaged over the range of frequencies.

That is, if L_{1A} increases 5 dB, then either ZE_L or 10 log A must also increase 5 dB to maintain the *same* indoor traffic noise level, L_{2A}.

A.2.12.2.4 Airborne sound insulation of entrance door of apartments

The transmission loss, presented in the form of a curve as a function of frequency, is evaluated by comparison with the reference curve of Fig. 7b in order to define the index DE_L. The reference curve was developed by *considering the spectrum of typical noises occurring the staircase* and the *sound absorption of furnished apartments* as a function of frequency. The method for comparing the transmission loss curve of the door and defining the index DE_L for the door is similar to the above described method concerning the transmission loss of external walls, windows and the index, ZE_L.

An approximate relation between the required index, DE_L and the staircase noise level penetrating through the door is as follows:

$$L_{1A} - L_{2A} = 22 + DE_L - 10 \log \frac{S}{A} \qquad (9)$$

where:

L_{1A} = A-weighted sound level in dB outside the door,

L_{2A} = A-weighted sound level in dB of noise penetrating through the door,

S = area of the door,

A, as in eQ. (8).

A.2.12.3 Required acoustical properties for partitions

A.2.12.3.1 Airborne sound insulation: Internal partitions

The Polish Standard is based on the assumption that the sound insulation of the partition is less important to the residents than the sound isolation between rooms, which depends on the transmission loss of the partition, as well as its area, and on the absorption in the receiving room.

Requirements for the transmission loss R_W of partitions are differentiated according to the partition area, S, in order to obtain approximately constant sound isolation between rooms. Requirements for partitions with areas most commonly used in typical buildings were used to set the basic requirements. Requirements for the acoustical properties of partitions are stated in terms of: the airborne sound insulation index, E_L, for walls; both the airborne sound insulation index, E_L, and the impact sound index, E_T, for floors. The requirements for partitions in a residential building are as follows:

- walls separating two rooms (regardless of the types of adjoining rooms)

For $S = 5 - 12^2$m , $E_L = - 1$ dB

For $S = 12 - 16^2$m , $E_L = + 1$ dB

For $S = 18 - 20^2$m , $E_L = + 2$ dB

- floors separating two rooms (regardless of types of adjoining rooms):

For $S = 8 - 18$ m^2, $E_L = - 1$ dB and $E_T = 0$

For $S = 18 - 23$ m^2, $E_L = + 1$ dB and $E_T = 0$

For $S = 23 - 30$ m^2, $E_L = + 2$ dB and $E_T = 0$

- walls separating an apartment from auxiliary rooms containing mechanical equipment for the building, or from stores located in the building:

For $S = 5 - 12$ m^2, $E_L = + 1$ to $+ 3$ dB

For $S = 12 - 16$ m^2, $E_L = + 3$ to $+ 5$ dB

For $S = 16 - 20$ m^2, $E_L = + 4$ to $+ 5$ dB

Note: Values of the index should be selected within the above limits according to the noisiness of the room.

- floors separating an apartment from auxiliary rooms containing mechanical equipment for the building, or from stores located in the building:

For $S - 18$ m , $E_L = + 2$ to $+ 4$ dB

For $S = 18 - 23$ m , $E_L = + 4$ to $+ 6$ dB

For $S = 23 - 30$ m , $E_L = + 5$ to $+ 7$ dB

Note: Values of the index E_L should be selected within the above limits according to the noisiness of the room; requirements for the impact sound index E_T should be selected individually according to the sources of noise and the location of noisy rooms.

- walls separating apartments from stairs or corridors

$$E_L = - 1 \text{ dB}$$

The Polish Standard does not specify requirements for walls within a dwelling, except for the wall separating a bedroom or living room from a bathroom or W.C. compartment; for this case, the required index $E_L = - 10$ dB.

A.2.12.3.2 Airborne sound insulation: External walls and windows

Requirements for the acoustical properties of external walls and windows are given according to the noisiness of the neighborhood. The standard specifies, as the measure of neighborhood noisiness, the average A-weighted noise level, L_{eq}, during maximum traffic noise, divided into the following classes:

– up to 60 dB
61 to 70 dB
71 to 80 dB

The requirements are stated in terms of the airborne sound insulation index ZE_L and apply to the external walls of the building and to windows, with the exception of staircase windows:

a) For neighborhood with average noise level up to 60 dB

- external wall $ZE_L = + 5$ dB
- windows of rooms $ZE_L = 0$
- windows of kitchens, bathrooms and W.C. compartments $ZE_L = 0$

b) For neighborhood with noise level from 61 to 70 dB

- external wall $ZE_L = + 10$ dB
- windows of rooms $ZE_L = + 5$ dB
- windows of kitchens, bathrooms and W.C. compartments $ZE_L = 0$

c) For neighborhood with noise level from 71 to 80 dB

- external wall $ZE_L = + 15$ dB
- windows of rooms (if percentage of glazing does not exceed 40%) $ZE_L = + 10$ dB
- windows of kitchen, bathrooms and W.C. compartments $ZE_L = + 5$ dB

A.2.12.3.3 Airborne sound insulation for entrance doors

Requirements for the acoustical properties of entrance doors of apartments are stated in terms of the index, DE_L, and are:

$$DE_L = + 5 \text{ dB}$$

The requirements for acoustical parameters of doors inside the apartment are not specified.

A.2.13 Czechoslovakia

A.2.13.1 Acoustical parameters of partition to be evaluated

The following acoustical parameters should be evaluated,

A.2.13.1.1 Internal walls

- transmission loss determined by the laboratory measurement, R'
- normalized level difference, D_N.

A.2.13.1.2 Floors

transmission loss (or normalized level difference), as for walls

normalized impact sound level, determined by laboratory measurement L_N (or by field measurement, L_N')

Required ranges of frequencies - similar to that given in CMEA.

A.2.13.2 Assessment criteria for acoustical parameters

The Czechoslovakian Standard recommends the application of assessment methods for the acoustical parameters of partitions similar to the methods given in CMEA. The indices E_L and E_T are determined by laboratory measurements, while indices from field measurements are marked E_L' and E_T'.

The standard specifies, in addition to the indices E_L and E_T, the indices I_L and I_T, whose numerical values are equal to the ordinate of the corresponding reference curve at 500 Hz (see ISO R-717). The following formulas give the relations among these indices:

$$I_L = E_L' + 54$$

$$I_L = E_L + 52$$

$$I_T = 68 - E_T$$

It should be noted that $I_L \neq I_a$ and $I_T \neq I_i$, because the methods for comparison of the measured curves with the reference curves are somewhat different.

A.2.13.3 Required acoustical properties of partitions

The requirements given in the Czech code are stated in terms of the indices E_L and E_T. The Czechoslovakian Standard is almost fully compatible with the CMEA Draft Recommendation RS 263-67 in the scope of required acoustical properties of residential buildings partitions. A slight difference appears in the requirement for the acoustical properties of walls inside the apartment; according to the Czechoslovakian Standard, the required $E_L = = 10$ dB, and in the CMEA RS 263-67, $E_L = - 9$ dB.

A.2.14 Rumania [51]

A.2.14.1 Acoustical parameters of partition to be evaluated

A.2.14.1.1 Walls

The transmission loss R (or R') is determined in octave bands in 1/3 octave bands according to Eq. (1).

A.2.14.1.2 Floors

a) The transmission loss, as given above for walls.

b) The normalized impact sound level beneath the floor, in octave bands (or in 1/3 octave bands corrected to octave bands) determined according to Eq. (12).

A.2.14.2 Assessment criteria for acoustical performance of partitions

A.2.14.2.1 Airborne sound insulation

The transmission loss, R, presented in the form of a curve as a function of frequency, is evaluated by comparison with the reference curves shown in Fig. 8a. The shape of the reference curves shown in Fig. 8a is similar to that of the curves in the ISO and the CMEA Recommendations. However, the Rumanian Standard does not specify numerical indices as in the ISO and CMEA Recommendations, or in the national standards of most other countries. Evaluation of the acoustical properties is based on comparison of the measured partition curve with the five "category curves" shown in Fig. 8a, establishing which of the curves best corresponds with the measured curve. Because of this approach, the curves R_1 - R_5 shown in Fig. 8a have the character of assessment criteria as well as requirements.

Methods for comparison of the reference curves R_1 - R_5 with the measured partition curve are similar to the methods already discussed, as follows:

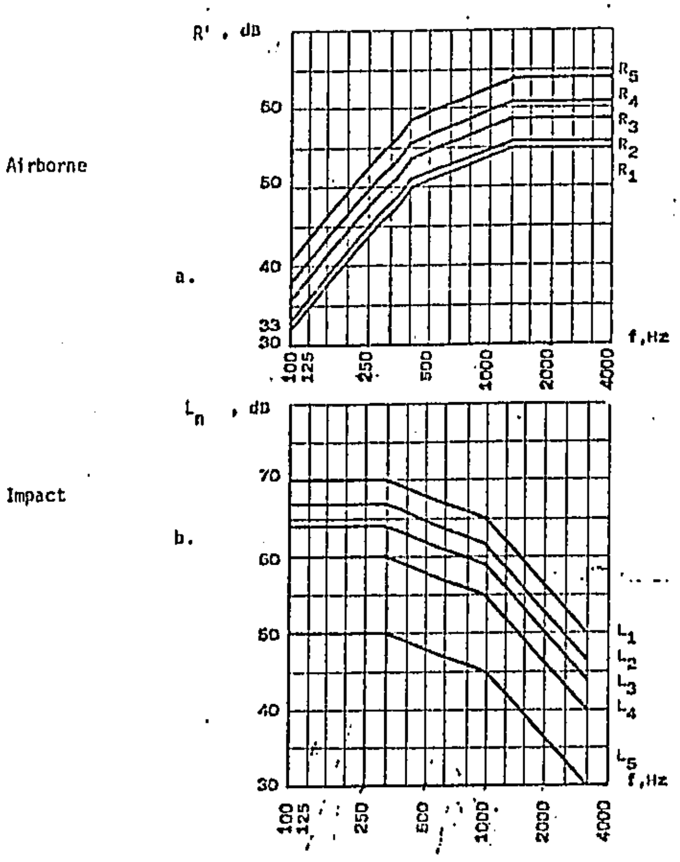

FIG. A.8. REFERENCE CURVES FOR ESTABLISHING CATEGORIES OF ACOUSTICAL QUALITY FOR AIRBORNE AND IMPACT SOUND INSULATION IN RUMANIA. THERE IS NO SINGLE-NUMBER RATING SYSTEM.

- The sum of the unfavorable deviations, divided by 15 for transmission loss values in 1/3 octave band (or by 5 for transmission loss values in octave bands), should be less than 2 dB,
- the maximum unfavorable deviation in 1/3 octave bands should not exceed 8 dB, or in octave bands, 5 dB.

A.2.14.2.2 Impact sound insulation

The principle of evaluation for the normalized impact sound level is similar to that for evaluation of the transmission loss of the partition. The standard presents five reference curves of impact sound level, $L_1 - L_5$, which have the nature of required curves of acceptable impact sound level. The curves $L_1 - L_5$ shown in Fig. 8b refer to the impact sound level in octave bands. Curve L_2 is identical to the reference curve shown in ISO R-717.

Methods for comparison of the curves of impact sound level with the reference curves are identical to the methods for airborne sound level.

A.2.14.3 Required acoustical properties of partitions

The required acoustical properties for internal partitions in a residential building depend on the desired category of acoustical comfort (two categories of acoustical comfort are defined):

	Category	
	I	II
• walls separating apartments	R_3	R_1
• floor separating apartments	R_3L_3	R_1L_1
• internal floors in apartments having two stories	L_3	L_1
• floors separating apartments from (quiet) auxiliary rooms in building	R_3L_3	R_1L_1
• floors separating apartments from (noisy) mechanical compartments of building, e.g., water-supply system.	R_4L_4	R_2L_2

The standard does not cover requirements for external walls, nor for internal walls inside the apartment.

A.2.15 East Germany (German Democratic Republic)

A.2.15.1 Acoustical parameters of partition to be evaluated

The acoustical parameters of the partition subject to evaluation are similar to those of CMEA Draft Recommendation RS 263-67, i.e.:

a) the transmission loss of partition, R (measured in the laboratory), or R' (measured in the field), according to Eq. (10 (LuftschalldämmMass).

b) normalized sound level difference, D_N (for non-adjacent source room and receiving room), according to Eq. (5).(NormSchalldrückpegeldifferenz).

c) normalized impact sound level, determined in 1/3 octave bands and corrected to octave bands (NormTrittschallpegel).

A.2.15.2 Assessment criteria for acoustical performance of partitions

Assessment criteria for the acoustical properties of partitions, determined in specified ranges of frequency, are similar to those in the CMEA Draft RS 263-67. The measured values of R (or R') and L_N serve for determination of the indices E_L or E_T. The following terminology is used:

E_L = LuftschallschütsMass,

E_T = TrittschallschützMass.

A.2.15.3 Required acoustical properties of partitions

The requirements for acoustical properties of partitions are stated in terms of the indices E_L and E_T. The required acoustical parameters of partitions in residential buildings given in the East German Standard are in principle similar to those specified in the CMEA Draft Recommendation RS 263-67. The only differences are as follows:

a) the required impact sound indices E_T are increased by 4 dB, compared to the values given in the CMEA Draft Recommendation. Such a requirement takes account of the possible ageing of the insulation material used for floors,

b) the required index, E_L, for walls separating bedrooms within an apartment consisting of three or more rooms has a minimum value $E_L = -20$ dB, and a recommended value $E_L = -5$ dB,

c) the acoustical requirements for floors of apartments having two stories are the same as for floors separating two apartments.

A.3 SUMMARY COMPARISON OF THE EVALUATION CRITERIA FOR ACOUSTICAL PROPERTIES OF PARTITIONS IN RESIDENTIAL BUILDINGS

1) The Regulations, International Recommendations and National Standards specify the following parameters for determining acoustical properties of partitions.

a) walls

- The transmission loss R, expressed in dB, measured in the laboratory without flanking transmission according to Eq. (1). The transmission loss is determined in 1/3-octave bands in the range of frequencies from 100 to 3150 Hz in all standards except the American Regulations, where the range is 125-4000 Hz. Determination of R in octave bands is allowable.

- The transmission loss R'_W expressed in dB, determined by field measurements (or laboratory measurements with flanking transmission) according to Eq. (1). The frequency range is as given above. The Polish Standard PN-70/B-02151 calls the value R'_W "approximate transmission loss". The American Standards do not allow for measurement of "approximate field transmission loss" in this way.

- Normalized level difference of acoustic pressure, D_N, in dB according to Eq. (5) or (10), with reference absorption $A_o = 10$ m², or reference reverberation time T_o = 0.5 sec.

The values of D_N are determined by field measurements. The French Regulations prescribe determination of the value D_N by laboratory and field measurements: results of laboratory measurements are calculated from formula (5) and results of the field measurements from formula (10).

b) floors

- The transmission loss R_W (or R'_W) and normalized level difference D_N are handled similarly as for walls.

- The normalized impact sound level L_N normalized to the reference absorption $A_o = 10\ m^2$, or to the reference reverberation time $T_o = 0.5$ sec. In the majority of standards, the level L_N is determined in the range 100-3150 Hz in octave bands (or 1/3 octave bands corrected to octave bands by addition of 5 dB).

The Finnish Standard [*54*], and the American and French Regulations do *not* prescribe correction to octave bands of the impact sound levels measured in 1/3 octave bands. It should be noted that the band width of measurement is not precisely specified in some of the standards and regulations.

2) All standards and recommendations, except the French Regulations, prescribe the assessment of the airborne sound insulation and impact sound insulation of a partition by comparison of the measured curves with reference curves. The French Regulations prescribe the assessment of the acoustical properties of a partition in terms of A-weighted sound levels caluclated from the values of sound insulation at all the measuring frequencies.

3) The majority of countries use in their standards reference curves of shapes similar to the shape of the reference curves of ISO Recommendation R-717. The curves given in the British, Dutch and Belgian standards differ somewhat from this shape (see Fig. 9).

4) Methods of comparison of the measured curves of airborne sound insulation (also isolation) and impact sound level with the reference curves in the different standards are similar. However, some differences occur: these differences in assessment of sound insulation amount to only about 1-2 dB for the same reference curves. The methods of comparison are as follows:

AIRBORNE

1. ISO, USA, W. Germany, Denmark, Sweden, Switzerland, CMEA, Poland, Rumania, Czechoslovakia, E. Germany: Minimum Requirement
2. CMEA, Poland, Rumania, Czechoslovakia, E. Germany: Better Quality
3. Belgium
4. England

IMPACT

1. ISO, USA, Switzerland, Sweden
2. CMEA, Poland, Rumania, Czechoslovakia, E. Germany, W. Germany, Denmark
3. Belgium
4. England

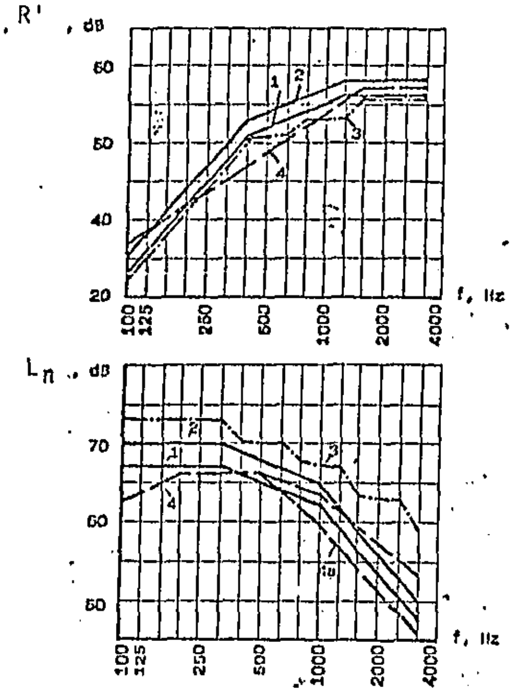

FIG. A.9. COMPARISON OF AIRBORNE AND IMPACT NOISE REFERENCE CURVES FROM VARIOUS COUNTRIES. THEY ARE SIMILAR TO ONE ANOTHER IN SHAPE, EXCEPT FOR THE IMPACT NOISE CURVE FOR THE NETHERLANDS.

Method A

To compare the measured values, the appropriate reference curve is shifted in steps of 1 dB towards the measured curve until the most severe of the following conditions is satisfied:

i) for curves determined in 1/3-octave bands, 100-3150 Hz,

$$1 \text{ dB} < \frac{\Sigma\delta_i}{16} \leq 2 \text{ dB} \qquad \text{(a)}$$

or for curves determined in octave bands, 125-2000 Hz,

$$1 \text{ dB} < \frac{\Sigma\delta_i}{5} \leq 2 \text{ dB} \qquad \text{(b)}$$

ii) for curves determined in 1/3-octave bands, 100-3150 Hz,

$$\frac{\Sigma\delta_i}{16} \leq 2 \text{ dB}$$

and (c)

$$\delta_{max} \leq 8 \text{ dB}$$

or for curves determined in octave bands, 125-2000 Hz,

$$\frac{\Sigma\delta_i}{5} \leq 2 \text{ dB}$$

and (d)

$$\delta_{max} \leq 5 \text{ dB} \quad .$$

Method A is used in the ISO Recommendation. Only the conditions (c) are used in the American Regulations.

Method B

To compare the measured values, the appropriate reference curve is shifted in steps of 1 dB towards the measured curve until both of the following conditions are satisfied:

$$1\text{ dB} \leq \frac{\dfrac{\delta_{100} + \delta_{3150}}{2} + \displaystyle\sum_{i = 125}^{i = 2500} \delta_i}{15} \leq 2\text{ dB}$$

and

$$\delta_{max} \leq 8\text{dB} \quad .$$

This method is used in the Draft Recommendation R.S.263-67, in the Polish Standard, the Czechoslovakian Standard, the USSR Standard, the Rumanian Standard, the German Federal Republic Standard and the German Democratic Republic Standard.

Method C

A mean unfavorable deviation of the measured curve from the appropriate reference curve less than 1 dB is required in *each one* of the following ranges of frequencies:

100 - 315 Hz
400 - 1250 Hz
1600 - 3150 Hz.

Method C is used in the Belgian Standard.

An analysis of the methods [*53*] has shown that if the unfavorable deviations of the measured value of a partition from the reference curve do *not* occur at the extreme frequencies, the conditions given in Method B are sometimes more severe than in Method A (the same sum of the unfavorable deviations is divided by 15 in Method B, by 16 in Method A).

If the unfavorable deviations do occur at the extreme frequencies, and if the sum of these deviations exceeds 4 dB, then Method A prescribes more severe conditions.

5) There are two tendencies in using the reference curves:

- to derive single-number assessment criteria of insulation (or impact sound level) measured as a function of frequency,
- as requirements for appropriate acoustical performance of a partition.

In the first case, the comparison of acoustical insulation of a partition (or impact sound level) with the reference curve defines an index, i.e., a single figure in terms of which the acoustical property of partition is evaluated. Acoustical requirements in such cases are stated in terms of the required minimum individual indices.

In the second case, the reference curves determine, for individual bands in the relevant frequency range, the required minimum insulation values (or the acceptable impact sound level) with unfavorable deviations allowable in certain ranges. In such cases, a series of the curves is given, determining the required acoustical parameters according to the proposed application of a partition.

6) The typical method for calculation of the indices is based on a comparison of the measured airborne sound insulation curves (or impact sound level curves) with the appropriate reference curve; the numerical value of the index is related directly or indirectly to the reference curve.

7) If one leaves out of account the slight differences in the calculation methods for the various indices, that is, the allowable deviations of the measured partition curve from the reference curve, it is possible to establish the following relationships among the indices:

a) airborne sound insulation

$$E_L = LSM \qquad (16)$$

$$I_a = STC \qquad (17)$$

$$I_a = 52 + E_L = \underline{52 + LSM = STC} - \text{for field measurements} \quad (18)$$

$$I_a = 54 + E_L = 54 + LSM - STC - \text{for laboratory measurements} \quad (19)$$

b) impact sound insulation

$$E_T = TSM$$

$$I_i = 68 - E_T = 68 - TSM \quad (20)$$

$$IIC = 110 - I_c + 5 = 115 - I_i \qquad I_i = 115 - IIC \quad (21)$$

$$IIC = 47 + E_T = 47 + TSM \qquad E_T = IIC - 47. \quad (22)$$

Note. In Eqs. (21) and (22), the IIC is calculated from the impact sound level determined in 1/3-octave bands; E_T and TSM from the impact sound level corrected to octave bands.

Discrepancies, resulting from different calculation methods, between the indices, as given in the above equations, amount to 1-2 dB.

8) A precise comparison of the assessment criteria for the acoustical properties of partitions is possible only by conversion of these criteria into airborne sound/insulation values (or into impact sound level values) expressed in A-weighted sound levels. Such a calculation can also demonstrate whether the criteria prescribed in the various standards are mutually consistent.

In order to carry out such calculations, a series of transmission loss curves and impact sound level L_N curves were selected, corresponding to the reference curves shown in Fig. 7 in such a way that the unfavorable deviations (within the allowable limits) occurred in different bands of frequencies. The following formulae were used for the calculations:

a) the "A-weighted airborne sound insulation, R_{EA}:

$$R_{EA} = 10 \log \left[\frac{\sum_i \quad 10^{0,1} \; (L_{fi} + K_{Ai})}{\sum_i \quad 10^{0,1} \; (L_{fi} - R_{fi} + 10 \log + \frac{S}{A} + K_{Ai})} \right] \quad (23)$$

where

i = index identifying the frequency band

L_{fi} = sound pressure level in the source room. A constant value, L_{fi} = 100 dB, was assumed for all frequencies.

R_{fi} = transmission loss of partition as a function of frequency, dB,

S = area of the partition, assumed to be 10 m^2

A = absorption in the receiving room, assumed equal to the reference absorption, A_o = 10 m^2

K_{Ai} = correction for each frequency according to the A-weighting curve, dB.

It should be noted that the results of calculations according to formula (23) do *not* depend on the absolute values of the assumed level L_i, but only on the shape of the noise spectrum in the source room. Previous analysis has shown that a "flat" spectrum (L_f = const.) gives results analogous to the speech spectrum. In fact, a "flat" spectrum is prescribed in the French Regulations for calculation of their "A-weighted" transmission loss.

b) the A-weighted impact sound insulation, L_{NA}:

$$L_{NA} = 10 \log \sum_i \; 10^{0,1} \; (L_{ni} + K_{Ai}) \qquad (24)$$

where

L_{ni} = normalized impact sound level as a function of frequency in 1/3 octave bands, normalized to A_o = 10 m^2

K_{Ai} = as in formula (23).

9) The results of calculations of the airborne sound insulation by the method described in item 8 are as follows:

a) Reference curve given in the ISO Recommendation (Fig. A.9a, curve 1): A transmission loss curve identical to the reference curve leads to R_{EA} = 52 dB. For transmission loss curves with unfavorable deviations from the reference curve within allowable limits (Method A, conditions a and b),

$$R_{EA} = 49 \text{ to } 52 \text{ dB} \quad .$$

b) Reference curve for *field* measurements given in CMEA Recommendation (Fig. A.9a, curve 1): A transmission loss curve identical to the reference curve leads to R_{EA} = 52 dB. For transmission loss curves with unfavorable deviations from the reference curve within allowable limits (Method B)

$$R_{EA} = 48 \text{ to } 52 \text{ dB} \quad .$$

c) Reference curve for *laboratory* measurements as given in the CMEA Recommendation (Fig. A.9a, curve 2): A transmission loss curve identical to the reference curve leads to R_{EA}= 54 dB. For transmission loss curves showing unfavorable deviations from the reference curve within allowable limits (Method B)

$$R_{EA} = 50 \text{ to } 54 \text{ dB} \quad .$$

d) Reference curve given in the Belgian Standard (Fig. A.9a, curve 3): A transmission loss curve identical to the reference curve leads to R_{EA} = 52 dB. For transmission loss curves showing unfavorable deviations from the reference curve within allowable limits (Method C)

$$R_{EA} = 51 \text{ to } 52 \text{ dB} \quad .$$

e) Reference curve as given in the British Standard (Fig. A.9a, curve 4): For an insulation curve in full conformity with the reference curve, R_{EA} = 52 dB. British Standard

CP3: Chapter III (1960) does not specify allowable unfavorable deviations from the reference curve but requires them generally to be "little". Allowing unfavorable deviations according to the ISO Recommendations, the values of R_{EA} are similar for the reference curves given in the ISO Recommendation and in the British Standard.

10) The results of calculations of impact sound level according to the method described in item 8 are as follows:

a) Reference curve given in ISO Recommendation (Fig. A.9b, curve 1): An impact sound level curve in full conformity with the reference curve leads to L_{NA} = 66 dB. For impact sound level curves showing unfavorable deviations from the reference curve within allowable limits (Method A),

$$L_{NA} = 66 \text{ to } 68 \text{ dB} .$$

Note: These calculations are based on the assumption that the reference curve refers to octave bands or to 1/3-octave bands corrected to octave bands.

b) Reference curve given in CMEA Recommendation (Fig. A.9b, curve 2): An impact sound level curve in full conformity with the reference curve leads to L_{NA} = 69 dB. For impact sound level curves showing unfavorable deviations from the reference curve within allowable limits (Method B),

$$L_{NA} = 69 \text{ to } 73 \text{ dB} .$$

Note: These calculations are based on the assumption that the reference curve refers to octave bands, or to 1/3-octave bands corrected to octave bands.

c) Reference curve given in the Belgian Standard (Fig. A.9b, curve 3): An impact sound level curve in full conformity with the reference curve leads to L_{NA} = 72 dB. For impact sound level curves showing unfavorable deviations from the reference curve within allowable limits (Method C),

$$L_{NA} = 72 \text{ to } 73 \text{ dB} \quad .$$

d) Reference curve given in the British Standard (Fig. A.9b, curve 4): An impact sound level curve in full conformity with the reference curve 4 leads to L_{NA} = 67 dB. An impact sound level curve in full conformity with the reference curve 4 (for soft floor coverings) leads to L_{NA} = 65 dB. The standard does not specify allowable unfavorable deviations. Allowing unfavorable deviations according to the ISO Recommendation, the values L_{NA} are lower (than those mentioned above), by 1 to 4 dB, according to the frequency range in which the unfavorable deviations occur.

11) It is clear, from the results of the calculations presented in items 9 and 10, above, that the determination of airborne and impact sound insulation properties of partitions in the form of indices, in the current assortment of standards, is not sufficiently precise. Differences of the A-weighted rating values that result from unfavorable deviations *within the allowable limits*, are as much as 1 to 4 dB.

12) Considering the results of the calculations presented in items 9 and 10, the relation between the indices and the A-weighted insulation values of partitions (when $S = 10\ m^2$ and $A_o = 10\ m^2$) can be expressed in the following approximate formulae:

$R_{EA} = I_a - (0 \text{ to } 3)$, dB (25)

$R_{EA} = E_L + (48 \text{ to } 52)$, dB - for field measurements (26)

$R_{EA} = E_L + (50 \text{ to } 54)$, dB - for laboratory measurements (27)

$R_{EA} = STC - (10 \text{ to } 3)$, dB (28)

$R_{EA} = LSM + (48 \text{ to } 52)$, dB - for field measurements (29)

R_{EA} = LSM + (50 to 54), dB - for laboratory measurements (30)

$L_{NA} = I_i + (10 \text{ to } 4)$, dB (31)

$L_{NA} = (69 \text{ to } 73) - E_T = (69 \text{ to } 73)$ - TSM dB (32)

$L_{NA} = (115 \text{ to } 119)$ - IIC, dB (33)

Note: The formulae (31) and (32) relate to the indices, I_i, E_T and TSM calculated from the levels in octave bands or in 1/3-octave bands corrected to octave bands. The formula (33) relates to the index IIC calculated from the levels in 1/3-octave bands.

13) The indices I_i and STC, and the related A-weighted values determine the acoustical properties of partition in the conditions in which they were measured (as concerns flanking transmission). The indices E_L and LSM, and the related A-weighted values, determine the acoustical properties of partition *with* flanking transmission. Calculation of the above indices based on field measurements includes the actually occurring flanking transmission; calculation based on laboratory measurements includes flanking transmission of 2 dB.

A.4 SUMMARY COMPARISON OF THE REQUIREMENTS FOR ACOUSTICAL PROPERTIES OF PARTITIONS IN RESIDENTIAL BUILDINGS

All the standards considered in this Appendix recommend acoustical parameters for walls and floors *between* dwellings. Acoustical parameters for partitions within one dwelling unit are not given in every standard. Some standards specify minimum acoustical properties of partitions separating dwellings from other noisy rooms situated in the building.

The Polish Standard and the French Regulations specify requirements for sound insulation of external walls. The Polish Standard prescribes requirements for windows and external walls, while the French Regulations concern only walls without windows.

A.4.1 Comparison of Approaches for Acoustical Properties of Internal Partitions

1. Standards and Regulations used in various countries specify differently the requirements for acoustical properties of internal partitions of residential buildings. The different acoustical parameters of partitions depend upon such factors as:

- noisiness of the housing area
- size of partition
- assumed acoustical comfort
- types of adjoining rooms.

The American Regulations specify acoustical requirements for partitions in a building according to outdoor noisiness of the housing neighborhood.

British, Rumanian, Czechoslovakian, USSR, and German Standards and the CMEA Recommendation specify requirements according to the desired acoustical comfort, independent of how noisy the neighborhood is.

The CMEA Recommendation and British, Rumanian, Czechoslovakian, USSR, German Standards do not use the categories "class of acoustical comfort" but specify "minimum" and "recommended" requirements. Differentiation of the requirements for the airborne sound insulation of the partition appears in the Polish Standard and indirectly in the Belgian Standard and French Regulations. This problem is further discussed in conclusions 2 and 3, below.

The American Regulations and West German and Belgian Standards cover requirements for acoustical parameters of partitions (also floor-ceiling assemblies) separating dwellings according to the types of room adjoining the partition.

A.4.2. Comparison of Required Acoustical Parameters of Building Partitions

A direct comparison of required acoustical parameters of partitions used in residential buildings, which appear in the various standards, is very difficult, because of the different assessment criteria for sound insulation of partitions used in these standards.

Comparison of these requirements is possible only in an indirect way, by comparing the sound insulation *in A-weighted sound levels between rooms* when the acoustical parameters of partitions just comply with the requirements given in the individual standards.

A.4.2.1 Walls separating dwellings

The group of European standards prescribe requirements for the acoustical properties of party walls that guarantee the following range of sound isolation between adjoining dwellings:

- minimum requirements (except British) 49-52 dB
- recommended requirements (higher quality) 51-54 dB

The British Standard prescribes a minimum requirement for sound insulation between dwellings of 47-48 dBA. The choice between minimum and recommended requirements depends exclusively upon the desired acoustical comfort. The Polish Standard gives only one requirement - a minimum of 50-51 dBA, the French and Belgian Standards 51-52 dBA. The recommendations used in the *United States* differ considerably from the European requirements. The difference results from the prescription of different requirements according to noisiness of the housing area. This approach is based on the assumption that outdoor noise penetrating into the dwellings helps to mask noises penetrating from adjoining dwellings. This approach might lead to further deterioration of the acoustical climate of dwellings which already have unsatisfactory acoustical conditions.

Average requirements given in the European standards are in the nature of minimum requirements for an *average noisiness of housing urban and suburban areas.*

The average required acoustical properties of partitions separating dwellings in U.S. for buildings situated in "noisy" areas are 2 dB *lower* than the minimum requirements in the majority of European standards. They are similar to the British minimum requirements.

U.S. requirements for the average sound insulation of partitions in the quietest neighborhoods are 2 dB *higher* than maximum European requirements.

The American Regulations, unlike many European codes, prescribe different requirements for sound insulating properties of walls according to types of rooms adjoining the walls. The differences in recommended values of sound insulation according to types of adjoining rooms are considerable, up to 7 dB.

The differentiation of requirements for walls separating dwellings in the U.S. according to types of adjoining rooms seems from the acoustical point of view undoubtedly correct. However, the use of such requirements for multi-family housing development, with application of industrialized technology, seems very difficult to most Europeans.

A.4.2.2 Floor-ceiling assemblies

The requirements given in European standards for the sound insulating properties of floor-ceilings are almost equal to the insulation requirements for walls (for airborne sound penetrating the floor):

• minimum requirements	48-51 dB
• recommended requirements	51-53 dB

The British Standard prescribes somewhat lower requirements (46-47 dB) just as for walls.

The American Regulations prescribe requirements for airborne sound insulation also, just as for walls.

European standards specify requirements for impact sound penetrating floors which may be expressed in terms of A-weighted impact sound level underneath the floor:

• for minimum requirements	70-73 dB
• for recommended requirements	61-67 dB

These requirements, as for airborne sound insulation, are not differentiated according to types of rooms except in the Belgian and West German Standards which differentiate the requirements according to types of rooms by ±10 dB with average (A-weighted) requirements of 62 dB.

The American Regulations prescribe differentiation of requirements for impact sound insulation according to the noisiness of the housing area. Assuming housing areas in 3 grades (see item 2), the following values of averaged A-weighted impact sound level can be cited,

highest requirements	60 dB
mean requirements	65 dB
lowest requirements	70 dB

The given values can differ by +10 dB and -5 dB according to the types of adjoining rooms.

A.4.2.3. Internal walls within a dwelling

European standards specify relatively uniform requirements for acoustical properties of partitions separating different dwellings, but requirements for the acoustical parameters of internal partitions within the same dwelling show considerable differentiation.

Many standards specify requirements only for walls separating living rooms from sanitary rooms. The required sound insulation varies from 30 to 45 dB; only the Belgian Standard increases to the sound insulation between living room and bathroom up to 45-52 dB. Similar requirements are given in the American Regulations, but the requirements are differentiated according to the noisiness of the housing area.

A relatively small number of European Standards specify minimum sound insulation between rooms within a dwelling. The Belgian Standard specifies the highest requirements in that the required sound insulation between rooms (except adjoining two bedrooms) is the same as for walls separating different dwellings. The Czechoslovakian and East German Democratic Republic Standards specify lower requirements: 30-40 dB (minimum values) and 40-45 dB (recommended values). The requirements given in the East German Democratic Republic Standard concern only the walls separating bedrooms from the living room in a dwelling consisting of more than 3 rooms.

The American Regulations give requirements which vary from 40 to 50 dB according to the noisiness of the housing area and to types of adjoining rooms.

A.4.2.4. External walls and windows

Requirements for external walls are given only in the Polish Standard and the French Regulations. The Polish Standard specifies requirements for walls and windows, and the French Regulations only for walls without windows.

The Polish Standard specifies the required sound insulation of external walls and windows according to the noisiness of the housing area, in terms of attenuation of outdoor A-weighted noise levels penetrating into rooms (for differentiated requirements) as follows:

20-25 dB
25-30 dB
30-35 dB .

The French Regulations prescribe A-weighted sound insulation of external walls without windows not less than 41 dB.

The standards discussed here pertain to the required acoustical parameters of partitions in buildings. Special consideration of flanking transmission in the construction of a partition is then necessary to meet the requirements. The problem is solved in the standards that state the required acoustical parameters of partitions in terms of indices E_L or LSM, since in the method for calculation of the indices, an allowance for flanking transmission of 2 dB is included.

The Belgian Standard specifies separately both the requirement for *transmission loss* of partitions (determined by laboratory measurements) and *normalized level difference* of partitions (determined by field measurements) taking into account the difference of 2 dB for requirements used in housing developments. The other standards do not consider this question.

Present experience in various institutions shows that:

- A-weighted sound insulation between dwellings below 49-50 dB causes serious complaints; this indicates that the minimum requirement given in many standards is about correct. The question of *recommended* higher values requires more precise analysis, based upon results of surveys or inquiries. Any increase of sound insulation, even if slight, above 49-50 dB requires (especially for concrete constructions) considerable expenditure of materials, causing an increase in weight and cost of the building. Still, the need for improvement of the acoustical performance over the minimum requirements cannot be overlooked.

- Requirements for acoustical parameters of *internal* walls in dwellings should be more precisely analyzed. It seems impossible and inexpedient to maintain the requirements for internal walls in a dwelling at the same level as for walls separating dwellings, as in the Belgian Standard. On the other hand, the use of very light constructions for the internal walls, leading to very low acoustical insulation, causes an obvious deterioration of the dwelling climate.

APPENDIX B

RESPONSES TO INTERVIEW/QUESTIONNAIRE ON ENFORCEMENT OF BUILDING CODE NOISE REQUIREMENTS IN EUROPEAN COUNTRIES

The Introduction of this report describes a series of interviews with European scientists who are concerned with noise requirements in building codes. This Appendix presents the results of those interviews, supplemented by subsequent correspondence, the recent technical literature, and further discussions.

Responses from the countries most actively concerned with enforcement of the code requirements are presented first, because presumably they have more to teach us, based on their wider experience even if they cannot all claim a high rate of success. In addition, it is also useful for us to know the directions currently being taken by countries that are not yet far advanced in this field; their responses are presented in the second part of this Appendix.

The countries that have relatively active programs for enforcing their building code noise requirements are Denmark, France, The Netherlands, Sweden, The United Kingdom, and West Germany. (The order is alphabetical; it does not signify intensity or effectiveness of the enforcement effort.)

The format of presentation, for each country, follows the order of topics in the interview questionnaire, which is presented as Appendix C of this report.

B.1 DENMARK

Information Sources:

Jørgen Kristensen,	Danish Building Research Institute Director, Building Acoustics Measurement Station (BAM) Copenhagen
Fritz Ingerslev	Danish Technical University Director, Department of Acoustics Lyngby

References 19-21

B.1.1 Official Documents

The noise requirements of the building code appear as Chapter 9, entitled, "Lydforhold," (Noise Conditions), of the Danish Byggningsreglement (Building Regulations), dated 1 June 1972. These regulations replace an earlier version, dated 1 August 1966, which replaced the original version of 1961.

Measurement practice follows the ISO procedures for the most part, except that normalization is to a reverberation time of 0.5 sec. As for the ratings, the fitting rules for the criterion curves are different (only 1 instead of 2 dB average unfavorable deviation, and an additional requirement for the average value over sixteen 1/3-octave bands must be met in addition); also, the shape of the impact criterion curve is quite different.

B.1.2 Status Of Documents

The building code has the force of law and applies officially to all of Denmark except Copenhagen, which has its own code. (The reason that Copenhagen does not follow the national code is its restriction on floor area in a single building.) In practice, however, Copenhagen follows the Danish national code in matters of acoustics and noise control.

A further revision of the code, planned for 1976, is expected to apply to all of Scandinavia, and will include Copenhagen, as well.

The noise control requirements apply to residential buildings (apartments and row houses, not single houses), hotels, hotel-pensions, homes for the aged, college dormitories, schools, and office buildings.

B.1.3 Summary of the Acoustical Requirements

For residential buildings, there are requirements for minimum acceptable noise reduction (level difference) between dwellings (normalized to T = 0.5 s.), both in terms of an *average* value over the sixteen 1/3-octave bands of interest, and a table of required values in 1/3-octave bands. The requirements for terrace or row houses are 3 dB more strict than for apartments. In addition, to provide assistance in planning the building, requirements are given for the (laboratory-measured) transmission loss of individual party walls and floors. (These "requirements" on transmission loss are for guidance only; the primary code requirement must be satisfied by field measurement of normalized noise reduction in the finished building.) Both an average value and a set of tabulated transmission loss values must be complied with; again the requirements on party walls for row houses are 3 dB more strict than for apartments. (There is no floor requirement for row houses).

In addition to the quantitative requirements mentioned above, examples are given of constructions that are deemed to meet the airborne sound insulation requirements.

Requirements are also given for the transmission loss of entrance doors. The code specifies average transmission loss of 30 dB as measured in the building, stating that this can be achieved if the door measures 34 dB in a laboratory test. In practice, the door is often spoiled by mail slots and leaks around the jamb, which are limited only by the rigorous fire law stating that slits wider than 1.2 cm must be fixed.

The impact noise insulation requirements (applying only to floors over dwelling rooms, not toilets, baths, basements, laundry, etc.) are stated in terms of a tabulated set of maximum acceptable impact noise levels in 1/3-octave bands, the same for all types of residential buildings. Examples are also given of floor structures that are deemed to meet the requirements.

There are requirements for maximum acceptable values of reverberation time in staircases and corridors, and examples are suggested for ceiling treatment that will lead to compliance.

Finally, there are limits on the noise levels from technical installations, like water pipes, central heating or air-conditioning, elevators, refrigerators, washing machines, etc., from spaces *outside* the dwelling. (Plumbing or an individual furnace within the dwelling need not comply).

For mixed land use (i.e., buildings containing both dwellings and shops), the local authorities may set up more stringent requirements on sound insulation for walls and floors than are specified in the code, but this is seldom done in practice.

For buildings other than dwellings, the same sound insulation, reverberation, and noise level requirements apply as for apartments, but instead of offering examples of constructions and treatments deeded to comply, the code apparently gives the architect free option to choose constructions that will meet the specifications. In non-residential buildings, the insulation requirement applies only from room to room, not room to corridor. The room-to-corridor field noise reduction test tends to show only the door performance, so the main emphasis is on the transmission loss of the corridor wall structure, as measured in the laboratory.

For schools, there are special requirements for the noise reduction between auditoriums or music rooms and other rooms.

B.1.4 Enforcement

The local city or county authorities are charged with enforcement of the code.

If a builder feels that the local authority is too strict in judging the field tests (i.e., if the test result is unfavorable), he can appeal to a higher level of government, particularly if the test results are not too bad.

If, in spite of local authority approval of finished row houses, the tenants find the sound insulation inadequate and go to court with test data (for example, measurements made by an acoustical consultant recommended by an association of civil engineers), the builder still has the responsibility to take remedial measures. In fact, this policy applies in *all* cases where the builder has *sold* the dwelling; it is harder to control if the occupants are only renting.

Approval for a building permit depends on a favorable review of the building drawings by the local authority. However, since their staff engineers usually have no acoustical training, there is considerable variation in effectiveness from town to town. The local building authority may require measurements in the finished building before the tenants may move in. In practice, some communities approve the drawings of residential buildings, before beginning construction, but only contingent upon successful acoustical tests in the finished building before occupancy. Such tests would be made by the Danish Building Research Institute (under Kristensen) or by the staff of the Technical University (under Ingerslev).

For new construction types (walls and floors), the building authority may require laboratory transmission loss tests, or alternatively, a noise reduction test in a single house, to which the code noise requirements do not apply (and therefore a relatively poor result would not be regarded as serious). Alternately, the tests might be requested by the architect's consultant.

As for the number of finished buildings actually tested for compliance with the noise requirements, it is hard to say. The government would like to have all buildings tested that involve more than fifty apartments; but this is, so far, not a strict law.

The Danish Building Research Institute tests about 50 to 60 buildings per year, usually in response to a request from the architect or engineer.....or sometimes because the local building authority has insisted that the architect request the tests.

In the buildings that are tested, if the first few sound insulation tests are satisfactory, only about three pairs of rooms would be tested. But if the results look bad or questionable, up to twenty room pairs would be tested. For the reverberation time in staircases, only one measurement is typically made; for impact noise transmission from the staircase to the living quarters, only one or two tests. Two or three doors would be checked for noise reduction. One or two impact noise tests from a balcony to the diagonally subjacent room would be made.

In cases where the sound isolation in the finished building fails to meet the code requirements, if the non-compliance is not very serious nothing might be done. But, technically, the local authority can insist upon correction of even slight failures, particularly if the tenant or the building owner complains. (It is by no means certain that buildings meeting the code requirements will provide adequate privacy; see the Introduction to this report.)

In practice, however, if the code requirement for transmission loss of the party walls and floors is complied with in the drawing inspection stage, then the primary code requirement for the normalized noise reduction in the finished building is usually met, unless the rooms are very large, or there is quite bad flanking transmission.

If the sound isolation turns out to be really bad, the building owner may sue the acoustical consultant for the cost of remedial work on the building, in which case the cost would be borne by the consultant's insurance company. (But some consultants don't wish to carry this kind of insurance, because they feel it would bespeak a lack of confidence in their own competence.)

Denmark has no tradition for lowering the rentals in buildings to compensate for faulty sound insulation, as is sometimes suggested. Only isolated cases are known.

As for the costs of the acoustical testing in the finished building, the building owner pays for these, just as he pays for other kinds of tests (soil strength, termites, etc.); he includes these costs with the other building costs and bases the rent structure on the total amoung.

B.1.5 Success of Code Enforcement

The Danish building code noise requirements have been in effect since 1961; ten years later only about 55% of the row houses and 50% of the apartments were meeting the code specifications. It is, in fact, only since the recent concern over pollution of all kinds that the authorities are beginning to take the noise control provisions of the building code seriously.

A study was undertaken by the Danish Building Research Institute in 1969 to discover the extent to which measured sound insulation in dwellings complied with the airborne and impact sound insulation requirements of the 1966 version of the code (scarcely different from the current code, for residential buildings). The survey covered twenty-two building estates with terrace houses, row houses and the like, a total of 180 units measured. Of these, only 43 units (=24%) met the 1966 code requirement for noise reduction. In only five of the twenty-two estates did more than half the units meet the requirement. Further tests indicated the presence of considerable flanking transmission; for many of the walls the average transmission loss was considerably smaller than the laboratory value for similar walls: less than 50% complied with the transmission loss requirements of the code.

Further field tests over the period 1957 to 1970 indicate a similar failure rate for airborne sound insulation in apartment houses, and also a significant number of failures in impact sound insulation. For details, see pages 10 and 11 of the reprint of Ref. 2, included as Appendix F of this report.

B.2 FRANCE

Information Sources:

Robert Josse, Director, Acoustics Division, Centre
Scientifique et Technique du Batiment
Grenoble

References 3-46.

B.2 OFFICIAL DOCUMENTS

B.2.1 The Regulations of 1969

Noise control requirements, to be observed in the design and construction of dwellings in France, are not collected together in a building code, as such, but are contained in a series of four brief orders or decrees, published from time to time in the Journal Officiel de la Republique Francaise, under the authority of the State Counsel, on behalf of the Ministers of Housing and Reconstruction, of the Interior and of Public Health and Population.

In Décret No. 69-596 of 14 June 1969 [31], setting general rules for the construction of all buildings to be used as dwellings, the Prime Minister states in Article 4: "Taking account of normal modes of occupancy, the isolation of dwellings ought to be such that the sound pressure level of noise transmitted into the interior of each dwelling does not exceed limits fixed by joint order of the Minister of Equipment and Housing and the State Minister of Social Affairs. Noise generated by any equipment whatever in the building outside the dwelling should not exceed limits fixed in the same form."

This enabling decree itself does not set any noise limits or requirements for sound insulation. The quantitative requirements are introduced in a separate order, the Arrêté of June 1969, relative to acoustical isolation in buildings for habitation [32]. In Article 1, it is stated that the A-weighted sound pressure level transmitted into the main rooms, kitchen and bath of a dwelling must not exceed 35 dBA when noise in the other locations of the building, taken separately, does not exceed, in each octave band, 80 dB, if the other location is a dwelling, 85 dBA if it is commercial, artisanal or industrial, or 70 dBA if it is a common staircase or hallway. Such noise is supposed to have a continuous spectrum covering the octaves centered on 125, 250, 500, 1000, 2000, and 4000 Hz.

This requirement, stated in terms of A-weighted sound levels, represents a legally simpler way of stating the requirements of the previous law, valid since November 1958: in that law, the requirements were stated in terms of the average values of the noise reduction, measured in 1/3-octave bands, and normalized to 0.5 sec reverberation time, in three ranges of frequency:

Low frequency (100-320 Hz)	D_n	=	36 dB
Middle frequency (400-1250 Hz)	"		48
High frequency (1600-3150)	"		54

With 80 dB in each octave band in the source room, this leads to approximately 38 dB in the receiving room, which (taking into account the 3 dB tolerance for measurement uncertainty, see Article 4, below) corresponds to the

35 dB requirement of this Arrêté.

Although this requirement is framed in terms of an A-weighted sound level, at present the A-level is not directly measured. Instead, the noise reduction is measured in octave bands and then the A-weighted sound level in the receiving room is calculated, assuming noise with 80 dB in each octave band in the source room.

This convention leads to a simply stated law but it entails a rather complicated measurement procedure. It is expected that in the near future, the practice will be changed so that A-weighted levels will be measured directly.

Article 2 states that the impact insulation of the floors, including the floor coverings, should be such that the (A-weighted) impact noise in the main rooms of the dwelling does not exceed 70 dBA when striking, dropping, or moving of objects or people excites impacts on the floor above similar in intensity, tread and cadence to those generated by the standard ISO tapping machine. In practice, of course, the test is conducted with the standard tapping machine impacting the floor.

Article 3 states that the A-weighted sound level generated in a dwelling by any equipment whatever in the building should not exceed 35 dBA in general, and 30 dBA if if concerns collective equipment such as elevators or heating.

Article 4 states that for the purposes of the present order, the sound pressure level should be measured in the center of the rooms, normally furnished, with doors and windows closed, the data being normalized to a reverberation time of 0.5 sec. To account for measurement uncertainties, a tolerance of 3 dBA is allowed.

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Article 5 charges the Director of Construction and the Director of Land Use and Urbanism with the enforcement of this Arrêté, each with respect to the matters that concern him.

The Arrêté of June 1969 is amended by another dated 22 December 1975. Article 1 of the 1969 Arrêté is modified to allow 38 dBA, rather than 35 dBA, in kitchens and baths under the prescribed conditions. Article 3 is changed so that the list of collective equipment in the building to which the 30 dBA noise limit applies is extended to include heating substations, transformers, water pumps, rubbish chutes, and mechanical ventilation systems (including outlets). In addition, noise generated in kitchens by any equipment in the building must be limited to 38 dBA, except that the noise of the mechanical ventilation system, with all outlets in the dwelling at minimum flow, should not exceed 35 dBA.

The four brief articles of the Arrêté of June 1969, amended by the Arrêté of December 1975, comprise the current national Regulations on noise control in French buildings.

B.2.1.2 The Acoustic Comfort Label

A fourth law, the Arrêté of 10 February 1972, which prescribes the attribution of an "Acoustic Comfort Label" to dwellings fulfilling certain improved acoustical conditions, is considerably more complicated, comprising 22 articles, as follows.

Generalities -- Definitions

Article 1

The supplementary loan, over and above the basic construction loan from the Loans Division of the Subsidized Rentals Organization, which is awarded when the quality of construction satisfies certain conditions of acoustic comfort, is determined according to the terms of the present ordinance as a function of the demonstrated quality of acoustic isolation in the dwellings.

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Article 2

When the quality of acoustic isolation in the dwellings is effectively determined, an "Acoustic Comfort Label" will be assigned to buildings for which the project manager has applied for the privilege at the time of filing the financial dossier. The Label comes in three degrees, corresponding to increasing levels of acoustic quality; the amount of the supplementary loan mentioned in Article 1 depends on the degree of quality.

Article 3

The levels of acoustical isolation characteristic of the Acoustic Comfort Label are determined according to Articles 4 to 11 below. The assessment of these requirements for the assignment of the Label is carried out according to the conditions given in Article 14 to 17 below.

Multi-Family Dwellings

Article 4

The sound level of noise transmitted between rooms of different dwellings in the same apartment house, when the noise level in the other spaces of the building, taken separately, is that defined in Article 1 of the Arrêté of 14 June 1969, must not exceed the levels given in the table below.

Airborne noise emitted in a locale outside the dwelling.

Source Room	Noise Level in Source Room	Maximum Permitted Sound Level in Receiving Room	
		Bedroom	Living Room
Bedroom	80 dB/OB	32 dBA	29 dBA
Living Room	80	29	32
Kitchen, Bath, etc.	80	27	29
Corridor	70	29	32
Commercial, industrial garage, public areas	85	32	32

Article 5

The isolation of floors against impact noise must be such that the sound level perceived under the conditions of Article 2 of the Arrêté of 14 June 1969 (excitation with standard tapping machine) does not exceed 67 dBA.

Individual Dwellings

Article 6

In the case of terrace or row houses, the noise level transmitted under the conditions of Article 4 should not exceed 27 dBA between adjacent dwellings. For the purpose of this Arrêté, buildings that do not include superposed dwellings are regarded as individual dwellings.

Article 7

The insulation of floors against impact noise should be such that the impact noise level perceived under the conditions of Article 2 of the Arrêté of 14 June 1969 does not exceed 64 dBA.

Generally Applicable Conditions

Article 8

The maximum noise level received in the part of the dwelling reserved for sleep should not exceed 35 dBA, when the noise level in the other parts of the dwelling is 70 dB in each octave. Such noise is supposed to have a spectrum identical to that defined in Article 1 of the Arrêté of 14 June 1969.

Article 9

The noise level generated by individual pieces of heating equipment, water heaters, or mechanical ventilation outlets in the dwelling should not exceed 30 dBA in the main rooms of the dwelling.

Article 10

The noise level generated in the main rooms of a dwelling by any equipment whatever in the building outside the dwelling should not exceed:

- 32 dBA in general
- 25 dBA, if it concerns collective equipment, such as elevators, heating, exchangers, heating substations, water pumps, transformers and ventilators.

Article 11

The acoustical isolation of rooms exposed to outdoor noise should be at least as great as the values in the following table The different facades, or parts of facades, are to be classified in three zones, I, II and III, depending on the noise level existing there:

Facade Zone:	I	II	III
Minimum Acceptable Acoustic Isolation:	42 dBA	33 dBA	---

The classification of the facade zone is determined by the Departmental Director of Equipment.

Monitoring and Measurements

Article 12

Examination of the drawings and other work necessary for the assignment of the Acoustic Comfort Label is the responsibility of the Minister of Equipment and Housing or by control organizations approved by the Minister of Equipment and Housing, by reason of their competence and objectivity. These control organizations intervene by delegation of the Minister.

The Ministry of Equipment and Housing designates a pilot control organization charged with coordinating the interaction of the

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various different control organizations called upon by the building firm, the project manager, or the services of the Ministry of Equipment and Housing.

The Services of the Ministry of Equipment and Housing reserves the right to have the pilot control organization make a certain number of measurements to verify the results obtained by the other control organizations. The number of these measures, in addition to those relating to appeals, should be at least equal to 10% of the total number of measurements made by the control organizations, in order to assure good coordination of the latter.

Article 13

The measurement methods to be used are those applicable to the Arrêté of 14 June 1969. The 3 decibel tolerance allowed by Article 4 of that Arrêté also applies to all of the measurements envisioned in the present Arrêté.

Article 14

The number of points attributed for premises whose acoustical isolation complies with the requirements of Article 4 to 11, above, is determined in accordance with the following table:

Compliance with the requirements defined in the following articles:	Number of points attributed
Multi-Family Dwellings	
Article 4	3
Article 8	2
Article 5	4
Article 10: Collective equipment, 25 dBA	3
General case, 32 dBA	2
Article 9: Individual equipment, 30 dBA	1
Article 11: Zone I, 42 dBA	5
II, 33 dBA	5
III, ---	—
Individual Dwellings	
Article 6	6
Article 8	2
Article 7	4
Article 9	1
Article 11: Zone I, 42 dBA	5
II, 33 dBA	5
III, --	—

Article 15

The control organization chosen by the project manager initially examines the preliminary plans for the buildings that will make up the project, in order to determine whether or not the construction is likely to be able to comply with the requirements for the Acoustic Comfort Label. From the results of this examination, the project manager can either withdraw his application for the Acoustic Comfort Label or proceed with the necessary improvements.

This examination is compulsory unless the project has been designed with the help of a technical research department or an acoustical consultant.

Article 16

When the building is completed, the control organization undertakes a series of acoustical measurements on a number of the dwellings selected in such a manner as to give a characteristic representation of the entire project.

These measurements form the basis of a report which states the number of points assigned to the project, in accordance with the table of Article 14.

Article 17

The "Acoustic Comfort Label" is awarded in three degrees, corresponding to increasing levels of acoustical quality: One Star, Two Stars, or Three Stars, according to whether the project under consideration has obtained a number of points:

- Greater than 40% but less than 70% of the maximum number of points that the project could possibly win (*);
- Greater than 70% but less than 100% of the possible number of points (**);
- Equal to 100% of the possible number of points (***).

For a number of points less than 40% of the maximum possible number, no Label is assigned, and no complementary loan money is awarded.

Article 18

The decision to assign the Acoustic Comfort Label is made by the Prefect, based on the report mentioned in Article 16, or he may delegate this decision to the Departmental Director of Equipment.

This decision can be revoked at any time, if he discovers that any of the Label requirements are not complied with.

Article 19

No one, whatever his official title, may take advantage of the Acoustic Comfort Label until the decision mentioned in Article 18 has been communicated to the project manager. In case this provision is not observed, the Label can be refused for this reason alone, in which case the project manager will know how to avoid a refusal to consider any subsequent petition.

Article 20

The increase in the amount of the construction loan mentioned in Article 1 is determined in accordance with the number of points awarded as in Articles 14 and 16, but never exceeds 6.50% of the principal loan. Each point of the Acoustic Comfort Label is worth 0.325% of the amount of the principal loan for projects under H. L. M. and P. L. R., and 0.26% for projects under I. L. M. and I. L. N.

Article 21

The provisions of the present Arrêté are applicable from the time of its publication, even to projects in construction but not finished.

Article 22

The Director of Construction, the Directory of the Treasury, and the Director of the Budget are charged, each with respect to what concerns him, with the enforcement of this Arrêté, which is to be published in the Journal Officiel de la Republique Francaise.

The Arrêté of 10 February 1972 was published in the Official Journal on 17 February, and has been the subject of much debate and discussion (see, for example, references 34, 38, 39, 40, 41, 42 and 43).

Although the Acoustic Comfort Label program in France has no legal force to *require* that all dwellings meet certain noise control specifications (as do the Regulations of 1969), its effect is to offer a prize to project managers whose buildings meet acoustical requirements, which, in fact, are rather severe.

B.2.2 Summary of the acoustical requirements

The Regulations of 1969 set requirements for the noise reduction between dwellings, depending on the use of the adjacent rooms, on the impact noise insulation, and on the noise generated by equipment in the building outside the dwelling. Measurements are actually made in octave bands, but A-weighted levels are calculated to determine compliance with the Regulations.

Similar, but more stringent, requirements are given in the law establishing the Acoustic Comfort Label, and, in addition, a procedure is given for calculating the amount of supplementary building loan to which the assignment of the Label entitles the building owner.

B.2.3 Enforcement

Since the Label requirements are not mandatory, this discussion covers only the enforcement of the noise control Regulations of 1969.

The Regulations are national law, so the Federal government has the responsibility for enforcement, through the offices of the Director of Construction for H. L. M. (Habitations á Loyer Modêré = town- and state-financed subsidized-rental housing).

In France, the builder and the architect are co-responsible (50-50) for achieving compliance with the Regulations in the finished building.

The drawings for H. L. M. housing are inspected to see that the construction is of an approved kind; there is, in fact, no routine acoustical testing in the finished buildings.*

The inspection of the building drawings is done locally in each of the (approximately) eighty Departments into which France is divided (one prefecture in each Department) by a local representative of the Director of Construction, in Paris. For very large projects, however, the drawings would be sent to Paris for inspection, usually by the staff of the Centre Scientifique et Technique du Batiment (CSTB), on behalf of the Director of Construction.

For housing *other* than H. L. M., there is no control of the sound isolation, and, as a rule, it is very good.

If a finished building fails to meet the requirements of the Regulations, it is not customary to require corrective measures unless the sound isolation is very poor, in which case the H. L. M. may finance remedial work.

The buyer of an apartment which turns out to have poor sound isolation can sue the builder in court, but he must present acoustical measurements, provided by himself, as evidence. If he is judged to have a valid complaint, the builder must pay the cost of the measure-

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*France has been included here in the group of "active enforcement" countries because of the originality of the Acoustic Comfort Label program, for which, of course, acoustical testing is required.

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ments and the court judges whether or not corrective measures must be taken by the builder.

Although routine acoustical testing is not the rule for code enforcement, CSTB has done a certain amount of testing in special research studies, so that the statistics of compliance of dwelling buildings with the Regulations can be assessed, as shown in Figs. 10 to 13 of the main text of this report. (The Acoustic Comfort Label is also discussed in some detail in the main body of the report.)

B.2.4 Success In Code Enforcement

Figure B.1 shows the results of airborne and impact sound insulation measurements made around Paris in 1962 (Ref. 35); a score of 0 is regarded as satisfactory.

It is evident that the majority of the test results are unsatisfactory. The poor results were attributed to the fact that, despite the existence of the earlier noise control regulations, limited construction budgets force higher priority to be given to matters other than acoustics in buildings. This situation was described as serious, even critical, since designing and constructing housing in such a manner as to provide adequate sound isolation is not a luxury but a necessity, whose importance has been affirmed by sociological studies. [*35*].

Section 4.2 and Figs. 10 to 13 of the main text of this report present statistical data on the distribution of test results for airborne and impact sound insulation in French apartment houses for two periods, 1960 to 1967 and 1969 to 1972. A comparison of the test results for these periods show the effect of adopting the French Regulations in 1969.

Two further sets of statistical data are shown in Figs. B.2 and B.3, dealing respectively with airborne sound insulation between bedrooms and other parts of the dwelling, and between the dwelling and public corridors.

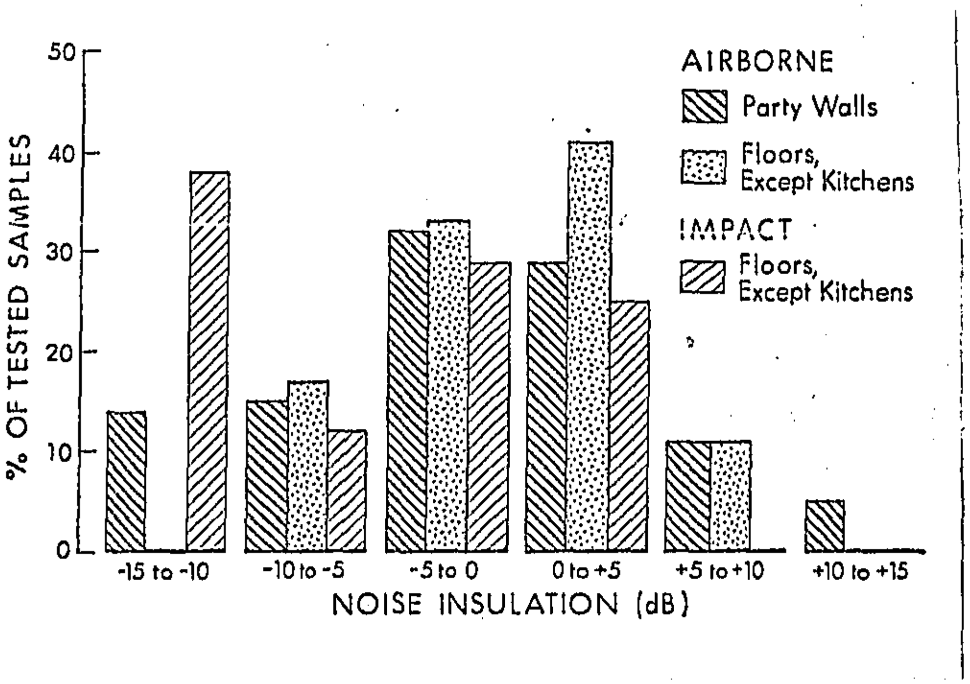

FIG. B.1. SOUND INSULATION MEASURED IN 25 DWELLINGS IN REGION AROUND PARIS (1962).

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AIRBORNE SOUND ISOLATION BETWEEN BEDROOMS AND OTHER PARTS OF THE SAME DWELLING [Article L8]

Number of Tests: 99

Comment: 45% of the tests met the Label requirement without invoking the permitted 3 dB tolerance.
60% of the tests passed with the tolerance.

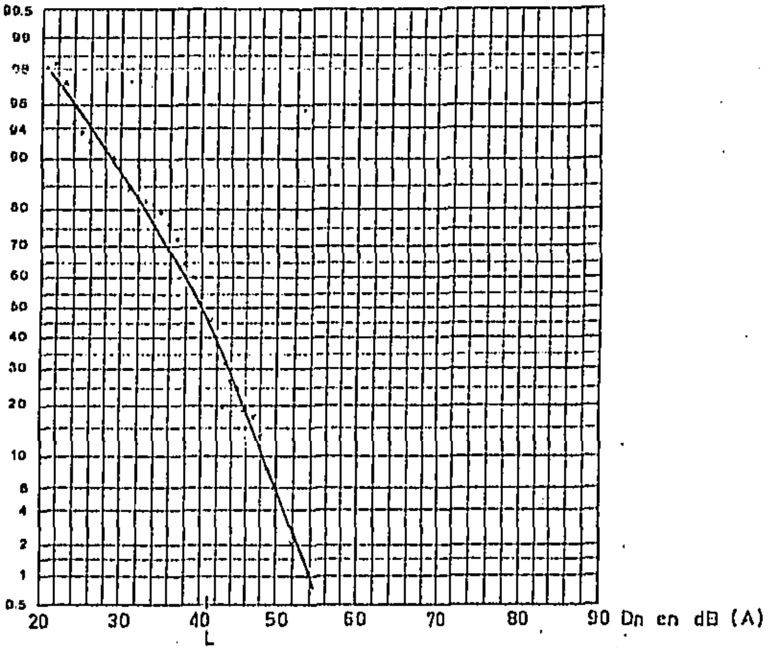

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FIG. B.2. DISTRIBUTION OF TEST RESULTS IN FRENCH FIELD TESTS (1969-72) OF NOISE ISOLATION.

AIRBORNE SOUND ISOLATION BETWEEN PUBLIC CORRIDORS AND DWELLINGS [Article R1 (L4)]

Number of Tests: 91

Comment: 76% of the tests met the Regulation without invoking the permitted 3 dB tolerance, but only 35% met the Label requirement.
89% of the tests passed the Regulation with the tolerance, but only 55% passed the Label requirement.

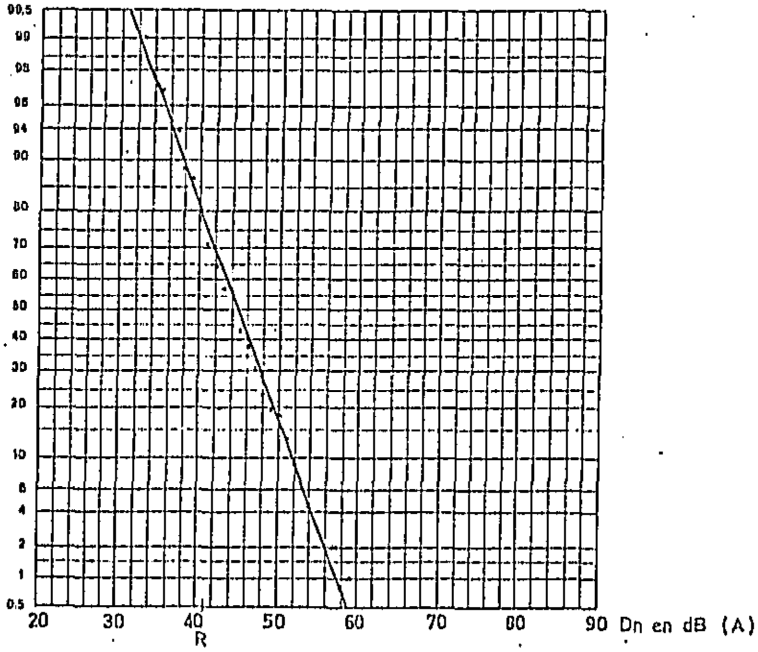

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FIG. B.3. DISTRIBUTION OF TEST RESULTS IN FRENCH FIELD TESTS (1969-72) OF NOISE ISOLATION.

Whether, in buildings that *do* satisfy the requirements of the Regulations, the tenants feel that they enjoy adequate privacy is altogether another question. CSTB has studied this matter [59], by combining measurements of airborne and impact sound isolation in dwellings in a number of towns in France (six for airborne sound, nine for impact sound) with the results of interviews with the occupants.

It was found in buildings that just meet the airborne sound isolation requirements, that about 60% of the occupants were unable to hear the radio or television of their neighbors; in buildings with about 5 dB better isolation, virtually none of the tenants was aware of the sounds. The correlation between the measured acoustical isolation and the subjective judgments of the occupants was very high.

With respect to overheard conversations from the neighbors, the scatter in the results was greater, but compliance with the Regulations led to greater satisfaction among the tenants: 90% instead of 60% were unable to hear the neighbors' conversations; not surprising in view of the fact that radio and TV are often played louder than ordinary conversational levels.

Despite the dispersion in the results, caused by differences in life-style, in sensitivity to noise, in homogeneities of construction, in background noise, etc., it was concluded that the index of acoustic isolation is a useful measure of acoustical protection. Moreover, it appeared that a building which just meets the requirements of the Regulations yields, on average, good isolation from the conversations of the neighbors; but it requires about 5 dB better isolation to give adequate protection against the noise of radio and television. It should be noted, however, that all of the dwellings involved in these tests were located in low background noise levels; thus, the degree of satisfaction expressed by the occupants probably represented minimal satisfaction. Greater satisfaction with privacy would be expected in noisier neighborhoods, a fact that has been confirmed by similar measurements made along exterior boulevards in Paris.

In the studies of impact noise insulation, the opportunity was taken to compare the subjective judgments of the occupants, concerning the freedom from intrusion of impact noise from the upstairs neighbor, not only with the then-current French impact noise index, but also with a number of other ratings of impact noise as well.

Ot was concluded that the French index of impact noise was *not* very reliable in predicting the tenants' judgment of impact noise intrusion. (Of course, this was due in part to the now well-documented inadequacies of the standard tapping machine, on which all the measurements were based [24].

It was found that better correlation with the subjective responses could be obtained with either B- or C-weighted sound levels, or with a rating similar to that of ISO but with a flat criterion curve, or with a rating similar to the French rating but ignoring the high-frequency range. With the rating then in use, it was found that the same value of the impact noise index might correspond to percentages of annoyed occupants anywhere from 10 to 60%, and that impact noises indices differing by 17 dB might correspond to the same degree of annoyance. (Similar findings have, of course, been reported from other countries [24].

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Thus, even perfectly effective enforcement of the current impact noise requirements of a building code based on the ISO tapping machine test, gives no assurance that the tenants will be satisfied with the protection against impact noise intrusions from their overhead neighbors.

B.3 THE NETHERLANDS

Information Sources:

Jan van den Eijk, IG-TNO, Assistant Director, Research
Institute for Environmental Hygiene,
National Dutch Research Institute, Delft.

G. J. Kleinhoonte van Os, TNO-TPD, Assistant Director,
Institute of Applied Physics, National
Dutch Research Institute, Delft.

J. N. M. van Rooijen, Bouwcentrum, Rotterdam.

References 22-23.

B.3.1 The Official Documents

Since 1962, there have been recommendations for noise control in buildings set out in a Code of Practice [22], but these are without legal force and are, in practice, unenforceable.

This Code of Practice is designated NEN 1070; the currently valid edition is that of December 1962 [22]. It is part of a series of documents under the general title, "Physical Foundations for Building Regulations," that were developed to provide technical background in the framing of building codes. There is, however, a draft revision dating from November 1973 [22] which is to be officially adopted in a month or so; the description of the Code provisions given in Appendix A of this report deals mostly with those of the new version, though some of the requirements in the still current version are also given. Both versions provide for two classes of acoustical isolation, "moderate" and "good".

In addition, there is a Dutch Uniform Building Code [23].

B.3.2 Status of Documents

The Dutch Uniform Building Code has picked up some of the provisions of the NEN 1070 Code of Practice; it applies to all new dwellings (not offices or schools), but specifies only the "moderate" class of requirements in the Code, and even omits part of those. These requirements are official and have legal force. They could be enforced by measurements in the finished buildings but in practice are not.

The Ministry of Subsidized Housing has its own requirements and recommendations, which are better than the Building Code requirements, but they, too, are based on the "moderate" requirements. These are enforceable in principle, but this is not often done.

In practice, even when the building design is aimed at the "moderate" criterion, the measured results usually do not come up to this level of performance, in part because the builders "don't know and don't care" about how the construction should be done in order to achieve the recommended results.

B.3.3 Summary of the Acoustical Requirements

With airborne and impact noise insulation ratings that differ considerably from those in the ISO family (based on five octave band levels, with fitting rules for measured and criterion curves quite different from the ISO rules, and a criterion curve shape for impact noise very different from that of ISO), the Netherlands Code of Practice in its original, currently-valid edition of December 1962, and also in the draft provision of November 1973 identifies two classes of acoustical quality, "moderate" and "good".

In the original Code (1962), there was a 3 dB difference between the two classes, only four octave bands (250-2000 Hz) were considered, and normalization was to 10 m^2 absorption. In the 1973 revision, the difference between classes is increased to 5 dB (3 dB was felt to be a meaningless distinction), the octave band at 125 Hz is added, and normalization is to 0.5 sec reverberation time.

Even as the draft revision is on the way to official acceptance, however, changes are still being made; and it is expected [60] that, when the revision of the Code is accepted, there will no longer be the two quality classes, but only minimum requirements (corresponding to the old "moderate" class) and the advice to use 5 dB stronger requirements.

Requirements are given, in terms of the Dutch insulation indices, for airborne and impact sound insulation between rooms not belonging to the same dwelling, in both quality classes. For impact insulation, the requirement applies only to the vertical direction in the "moderate" class, so there could be serious problems with impact noise transmission along a "bath-diagonal-to-bedroom" path. The impact requirement in the "good" class applies in all directions, as do all the airborne noise insulation requirements.

Recommendations are given for means to prevent banging of the entry door, and rattling of metal bannisters, for caulking and resilient treatment of plumbing and heating penetrations, for sound absorptive treatment in the stairwells, for floor-covering for common corridors, airborne sound insulation of entry doors, and for insulation between sensitive rooms *within* a dwelling.

In addition, specific wall and floor constructions are recommended that are deemed to comply with the Code requirements, although the basic quantity governing acceptance is based on normalized noise reduction in the finished building.

A special feature of the Dutch Code [*61,62*] is its realistic approach to the variation encountered in any series of acoustical measurements. The sound insulation values for a large number of identical specimens would not all be identical, but would show a certain scatter. Therefore, the decision to use a *new* type of wall or floor construction between dwellings should not be based on the results of a single measurement, because this particular measurement might happen to deviate considerably from the mean for the group. As more measurements are made, the mean and standard deviation can be more closely defined. In the meanwhile, if only one airborne sound insulation measurement for the new construction is available, for example, the results should be decreased 1 dB for laboratory measurements and 3 dB for field measurements to account for the scatter, and the laboratory results must be further reduced by 2 dB to account for flanking transmission in the field, before calculating the insulation index. As the number of available test results increases, the scatter correction diminishes.

No such correction is made for the results of impact noise tests.

B.3.4 Enforcement

The Dutch Uniform Building Code covers only the building drawing inspection stage, to assure that approved constructions have been selected. It usually does not envision tests in the finished building to demonstrate adequate sound isolation, though in a few towns (e.g., Utrecht and Rotterdam) test measurements are carried out, usually with not very good results.

In reviewing the drawings, local city officials have some guidance from the Code of Practice, NEN 1070, with a list of constructions that would yield adequate isolation with normal flanking conditions. But since only three examples of wall construction and four for floor construction are offered, the officials frequently find themselves on unfamiliar ground.

For new constructions, preliminary tests would be required by the local official at the TPD-TNO laboratories. For a radically new construction, the building *elements* would be tested first, then a few pilot rooms in buildings, and finally a whole apartment house.

Sometimes, a slip-up occurs even in so routine a task as inspection of the drawings. The main difficulty is that there are not enough people for drawing inspection to keep up with the number of buildings being built, and certainly not enough staff to conduct routine acoustical measurements in the finished buildings. Furthermore, the responsibility in case of failure to comply with the Code is unclear (as opposed to Sweden, for example, where the responsibility is arbitrarily laid on the builder).

Technically and scientifically, the problems are not great. But there are not enough technical people available to realize the possible gains. Moreover, it is impossible to insist on special acoustical treatment in a buyer's housing market. There is still a long way to go to re-educate the builders.

A particular problem has been the so-called "Volkswagenbouw", which is Government subsidized housing with barely adequate funding. If any expenditure at all were made for improved acoustical isolation, the housing simply could not be built.

In The Netherlands, as elsewhere, although in principle all the sound insulation problems are solved with the approval of suitable constructions at the drawing inspection stage, in fact difficulties invariably occur during construction, with the installation of continuous heating runs, television leads, etc., where the sound leaks are hidden once the finish trim is applied.

A negligible percentage (less than 1%) of finished buildings are tested for sound insulation. The Institute of Applied Physics (TPD) in Delft measures only 70 to 80 dwellings per year; the Research Institute for Environmental Hygiene measures about 150, and Rotterdam makes about 150 measurements compared with 30,000 new dwellings per year. About 5 to 10% of the rooms in a dwelling are tested.

Of the buildings tested, about 40 to 50% fail to comply with the Building Code. In cases of failure, ordinarily no corrective measures are taken unless the failure is extreme; and no tradition exists for modifying the rental in compensation for poor sound insulation.

TPD has developed a quick "spot check" for sound insulation, by looking only at the results for the 500 Hz octave band. From the 70 to 80 complete tests that are performed each year, the 500 Hz data are taken as a basis for spot checks in other buildings. (For impact insulation, the 2000 Hz octave band is used.) The cost of spot testing is only about 10 to 20 Dutch florins ($3 to 6) per wall or floor. In one night, TPD has tested as many as 130 to 140 walls!

In the last analysis, the primary resistance to effective noise control in The Netherlands is economic. For government funded housing, the builder may have to spend up to 400 Dutch florins ($150) per apartment for acoustical measures, such as sound absorptive treatment in the stairwells, floated floors, plugging the holes in the central heating runs, etc., in order to meet the "moderate" quality requirements. An additional 400 florins per apartment would be required to meet the "good" quality.

Stated in terms of initial cost in this manner, these estimates often discourage builders from attempting to comply with the noise requirements. However, if it is pointed out that the "good" quality class can be achieved at no greater cost to the tenant than an increase in his rent equal to the price of a package of cigarettes per week, the project seems more reasonable [63].

Although, as described here, the noise control enforcement picture in The Netherlands looks discouraging at present, the same is true in some other countries that have nominal enforcement programs. It is only in the last few years that any serious attention has been paid to the question: although the laws and the Code of Practice have been on the books for many years, there has been no push, during post-war reconstruction, for strict (or even haphazard!) noise control enforcement.

For example, although there exist many records of individual sound insulation tests, there has been no effort to pull these results together for a public evaluation of the current status of privacy in homes. Preparing just such a report is one of the current tasks of the Dutch Society Against Noise (founded in April 1970, a group made up of the Dutch Society of Engineers, the Dutch Acoustical Society, and others, following a Congress on noise annoyance).

The existence of such anti-noise groups and of highly competent technical staffs at TNO-TPD and IG-TNO will form the backbone of an effective Dutch noise control program in building code enforcement if and when the demand appears.

B.4. SWEDEN

Information Sources:

Bertil Sundberg,	Head of Building Physical Section, National Board of Urban Planning, Technical Department, Stockholm.
Sten Wahlstrom,	Royal Institute of Technology, Division of Architectural Acoustics, Stockholm, Sweden.
Sven Lindblad,	Professor and Director of Building Acoustics Institute, Lund Technical University, Lund, Sweden.
Bjorn Lundqvist,	Svensk Akustikplanering AB, (Acoustical Consulting), Gothenberg; also member of faculty of Chalmers Technical University, Acoustics Department, Gothenberg, Sweden.

References 11 to 16.

B.4.1 The Official Documents

The current regulations for sound insulation came into force in Sweden on 1 January 1976; they are included in the Swedith Building Code SBN 1975, Chapter 34, entitled, "Ljudklimat" (Noise Climate [11,12]). These regulations replace an earlier version given in the Svensk Byggnorm 67 (SBN 67 [15]).

The main regulations for all building activity in Sweden are included in the Building Act of 1947 and the Building Ordinance of 1959. Details concerning design and construction are given in *special regulations* which are revised and supplemented as required. The task of issuing such regulations has been, since 1 July 1967, the duty of Statens Planverk (the National Board of Urban Planning) which is the central authority for planning and building in Sweden.

The publication "Svensk Byggnorm 67" (the detailed regulations mentioned above) consists partly of regulations which are compulsory, both for the builders and the authorities, partly of recommendations and directions which are optional. The regulations are typographically distinguished from the recommendations and directions by their larger typeface and column width.

Svensk Byggnorm 67 was written by the Technical Department of the National Board of Urban Planning, with the assistance of the Technical Council of the Board, specially appointed technical committees and other experts. Consultation has also taken place with building trade organizations and with central and local building authorities. An attempt was made to give the regulations the form of functional requirements, connected to general and objective test or calculation methods, and to co-ordinate all rules in the field of building design and construction.

Supplements and alterations to Svensk Byggnorm 67 are published from time to time in the series Svensk Byggnorm, together with comments and other information (e.g., Ref. 16). In this series is also published information concerning centrally approved buildings, building components, fire-classified products, etc.

The Building Act of 1947 and the Building Ordinance of 1957 are still effective, but (until the recent SNB change of 1/1/76), the details concerning design and construction of acoustically satisfactory dwellings were given in Svensk Byggnorm 67 and Supplement SBN-534:6. The Building Act, the Building Ordinance and SBN 67 (now SBN 1975 are all valid at the national level. Thus, they apply uniformly throughout Sweden.

B.4.2 Status of Documents

The Building Act and the Building Ordinance are law; SBN 67 and its recent revision are partly requirements and partly recommendations.

Many houses are financed by government funding and in order to qualify, these must comply with all of the SBN requirements, according to government rules. However, even if the building is not Federally funded, the local authorities can enforce compliance with the SBN noise control requirements in multi-family dwellings.

B.4.3 Summary of the Acoustical Requirements

SBN 67 and the recently adopted revision SBN 1975 give requirements for maximum acceptable noise levels, and required value for airborne sound insulation index, I_a, and for impact insulation index, I_i; these apply to row houses, apartment houses, hotels, hospitals, schools and office buildings. SBN 1975 also specifies maximum acceptable reverberation time in the common staircases. Supplement SBN-S 34:6 gives a comprehensive catalog of examples of wall and floor constructions (with construction details) that are likely to satisfy the noise requirements.

B.4.3 Enforcement

In Sweden, the builder is ultimately responsible for compliance with the building regulations, but the architect and the various contractors have part in the responsibility.

The financing and the building permit are contingent upon satisfactory review of the building plans and drawings.

Before a building is built, all drawings must be sent to the local building office, to check for compliance with the requirements. The local official refers to SBN Supplement 1 [*16*] to see if the proposed construction agrees with the recommendations.

New constructions must be first tested in the laboratory, then in an experimental house, before being approved, and subsequently the sound isolation must be checked in the finished building. It has been found, however, that the laboratory test is often the least important, because flanking transmission so often governs the field results. If only a small change from familiar constructions is involved, the builder may go straight to tests in a small-scale actual house, and then to the project proper.

An answerable organizer of the construction work must accept responsibility for the workmanship; his competence is judged and approved by the local construction board. Later on, the Board would normally not have time to keep up with all the details of construction.....though some large projects are controlled more closely.

Compliance tests of airborne and impact sound insulation are made in about 5% of the finished buildings, on average, throughout Sweden; about 15% of the rooms are tested in the buildings that come under test. In Stockholm, the average percentages are 15% and 15%. More than

1000 tests per year are conducted in Stockholm.

In practice, the percentage of rooms tested depends on the early test results; if all of the units comply, they stop testing, usually at less than 10%.

In evaluating the results of field tests of airborne and impact sound insulation, the following rules are observed (taking account of measurement inaccuracies):

a. A construction is approved even if the normal requirement concerning 8 dB maximum unfavorable deviation is not met at 100 and 125 Hz, for airborne insulation, or at 2500 and 3150 Hz for impact insulation.

b. Generally, a construction is accepted if the maximum unfavorable deviation is 9, rather than 8 dB. (It is generally conceded nowadays that this "8 dB maximum unfavorable deviation" rule is actually a mistake for airborne sound insulation ratings; it is being dropped from the next revision of ISO R 717. For impact sound insulation, however, the 8 dB rule should be kept, because for wooden floors it exercises some useful control on the impact noise levels at frequencies *below* the normal range of test frequencies.)

c. In certain cases, even a 10 dB maximum deviation is accepted, if it occurs in the 160, 200 or 250 Hz band. If greater deviations occur, however, the fault must be corrected and a repeat test made to demonstrate compliance.

Theoretically, if the finished building fails the sound insulation tests more seriously than the allowances above, the builder "must rebuild the house." If the preliminary drawings were approved as showing suitable basic constructions, then any serious discrepancy in the finished building must be a "clumsy goof" and rather simple to correct. At any rate it must be done.

No attempt is made to adjust the rental in such cases; there is a strong feeling that there should be free exercise to allow the market to govern the rentals.

If the Public Building Authority requests certification of a building construction, generally the builder must pay for the certificate of compliance, including any testing that may be required. In Stockholm, the Public Housing Authority provides acoustic testing services themselves.

As for the cost of improved sound isolation required under the code, this must be borne by the builder; but since the same requirements are imposed on everyone, he suffers no competitive disadvantage.

In many cities, the cost of tests to demonstrate compliance is covered by the charge for the building permit. Also, the architect and the answerable organizer for the project have insurance that covers some of the costs.

B.4.4 Success of Code Enforcement

Existing figures on the number of buildings that fail to comply with the noise control requirements always tend to be biased, because the measurements are not made at random, but rather in situations where trouble is expected. Thus, the following percentages, dating from 1970, probably overestimate the typical failure rate, by an unknown amount.

Stockholm		Percentage of room pairs failing to comply
Airborne insulation:	vertical	5%
	horizontal	5
Impact Insulation		5
Other cities		
Airborne insulation:	vertical	20%
	horizontal	15
Impact insulation		15

The National Board of Urban Planning systematically maintains a collection of field acoustical measurement results, made by the building authorities, cooperative building societies, builders and consultants. The measurements have become the basis for such publications as Supplement 1 to SVB 67 [16], cataloging the building constructions deemed likely to yield satisfactory isolation.

B.4.5 General Comments

At present there is active collaboration between Sweden and the Nordic Building Regulations Committee (NKB), an association of national building authorities from Denmark, Finland, Iceland, Norway and Sweden. The object is to coordinate and unify the technical building regulations in the five Scandinavian countries.

Sweden accepted the ISO sound insulation procedure (R 717) in 1968; Denmark and Norway have not yet accepted it, though Denmark is currently moving in that direction [21].

Within Sweden, it is clear that the rate of success with noise control in buildings is significantly greater in Stockholm and other large cities than elsewhere. Particularly, there may be some large discrepancies in the north of Sweden; but in such places the materials and the construction methods tend to be quite conservative, not experimental, so the number of serious failures is probably not large.

As for anticipated changes in the formulation or enforcement of the noise control requirements for buildings, it is felt that, although the record of success is not perfect in Sweden, it is still pretty good, and there is not much incentive to change the current procedures.

One final note of interest: there is a general arrangement whereby a certain percentage of the building cost in Sweden is levied to pay for new research in buildings, including acoustics. Earlier, the levy was 0.6%, then 0.4% and now 0.5%. The money is distributed through the Swedish Institute for Building Research to various consultants and institutes to pay staff salaries and research costs for the study of specific problems.

B.5 THE UNITED KINGDOM (England and Scotland, Inner London)

Information Sources:

George Vulcan, Greater London Council, London.

B.5.1 The Official Documents (England and Scotland)

A Code of Practice [29] has been in effect in the United Kingdom since 1960; it specifies criterion curves for airborne and impact sound insulation for three grades of construction: one (the most severe) for house party walls (HPW); and two for apartments, the better grade (I) corresponding to the expectancy that the tenants will not find noise any worse than the other inconveniences of apartment living, the lesser grade (II) such that the tenants will likely find noise the most annoying aspect of apartment living (in other words, a truly minimal requirement). These criterion curves are illustrated in Fig. 5 of the main text.

The Statutory Instruments of interest are "The Building Regulations," issued separately for England (outside of inner London [65]) and for Scotland [66].

B.5.2 Status of Documents

The Code of Practice has no legal force. And the London Building Acts and the various Constructional By-laws made under them exercised no control at all over sound insulation.

Thus, it was not until the Building Regulations of 1965, revised in 1972 [65], that British sound insulation requirements gained the force of law. The Building Regulations adopted the Code's HPW criterion curve to apply in all dwellings that share common wall with another dwelling. Requirements affect non-dwellings only if adjacent to dwelling (office, shop or pub).

B.5.3 Summary of the Acoustical Requirements

The British Code of Practice sets up several criterion curves, both for airborne and impact sound insulation, of varying degrees of strictness. The shapes of these curves and the manner of fitting curves of measured data to them are different from the ISO family of ratings. In fact, it is not the purpose of the curves of the British Code to establish a single-number rating scheme at all, but rather to identify minimum acceptable acoustical performance in several Grades. A wall or floor must conform, according to certain rules, to one of the Grade curves in order to be deemed acceptable.

Reference to a footnote in Appendix C of the Code of Practice: Chapter III shows that a small amount of tolerance is permitted on the grading requirements, but the amount of the tolerance is not stated. However, a definition included in Ref. 64 shows that a maximum total adverse deviation of 23 dB is permitted.

The Grade for a partition is assigned by superimposing a curve of measured transmission loss (or impact noise level) upon the Grade curve in question; if the sum of the unfavorable deviations is no more than 23 dB, the partition meets that grade.

As far as the Building Regulations are concerned, only one Grade is significant; where they apply, they aim at the HPW Grade, irrespective of the type of dwelling. It is desirable, even where it is not mandatory, that forms of construction complying with the HPW Grade should be used.

The performance of a given construction must be based on the average performance in field tests of at least four different specimens of the construction in question. The test procedure is that for noise reduction in 1/3-octave bands, normalized to 0.5 sec reverberation time in the receiving room, D_{nt}, according to British Standard 2750: 1956, with Amendment PD 5065, October 1963, Sections 2 A and 3 A and Clause 3e(ii). There is some ambiguity about this, however; sometimes it is implied that transmission loss, rather than the normalized noise reduction, is involved.

It is clear, however, that the Regulations aim to achieve adequate sound isolation in dwellings by specifying "deemed to comply" building elements, selected on the basis of field tests, rather than relying on field tests to demonstrate compliance.

B.5.4 Enforcement

Enforcement of the Building Regulations amounts to a "deemed to satisfy" judgment of the various construction elements before the building permit is issued. The local building inspector is responsible for enforcement; he is bound to follow the Building Regulations but must refer to the Building Authorities before taking any infraction to court. His judgment would ordinarily be based on the field data published from time to time in the Building Research Station Digest, for various common constructions. But for novel constructions, particularly on a large project, the inspector might give special approval (based on agreement by the Building Research Station) for buildings, say, four units for field test before giving final permission for the entire project. Approval for the building permit depends upon the favorable review of the inspector.

There are normally no measurements in the finished building to test or demonstrate compliance with the Regulations. Only if bitter complaints arise would tests be made.

If a building should happen to fail to meet the Regulation requirements nothing is ordinarily done. In principle, if the complaining tenant could prove that the builder failed to comply with the approved design, then the builder could be required to correct the faulty construction. In practice, this is so difficult as to be unfeasible.

B.5.5 Success of Code Enforcement

A series of measurements by the Building Research Station was carried out in 1972-73, following the adoption of the new Regulations, to gather sound insulation data for new buildings for comparison with earlier pre-Regulations data. It was found that the percentage of units failing the requirements of the Regulations was about 50% and increasing.

One reason for the rising rate of failure has to do with the misuse of a special type of brick used in British walls. This brick has a hollow indentation called a "frog" on one of the large faces. It is intended that the frog should face upward, as the wall is built, to catch mortar and improve the keying. The recent tendency has been to lay the brick upside down (to save mortar presumably) so that the frog remains hollow and the weight of the wall drops from the required 85 lb/sq ft to 70 or less, with no means of measuring the as-built weight of the construction.

At present, there appears to be no plan to modify the British noise control enforcement procedure.

There has been talk of the need for a new social survey to try to correlate people's judgments of the adequacy of their sound isolation with physical measurements in the buildings; but such surveys are very expensive, and the economy is not thriving.

B.5.6 Inner London

A special case exists for inner London, which has different rules from the rest of England under the Greater London Council (formerly London County Council).

Sound insulation requirements are smuggled in as part of the fire by-laws, which affect all buildings. Party walls (dividing two semi-detached houses) are required to be constructed with 9" brick, to achieve the required fire resistance. For separating walls, that divide two apartments within the same building, the Council has adopted a Building Research Station construction meeting Grade II, though there is as yet no formal written requirement.

It is stated that all Council flats in London are built to very high standards, and that generally, for separating and party walls and floors, the fire resistance requirements lead to good acoustical isolation: "noncombustible construction plus 1 hour minimum fire test" (which may go as high as 2 or 4 hours, depending on height).

As for enforcement, there are 28 districts under a single district surveyor, responsible for compliance with the fire laws. This district surveyor has statutory power in his own right and can take court action without reference to any other authority.

In case of failure to comply with the by-laws (during or after construction), he may give notice that compliance must be achieved within a fixed time or he will take the matter to court. (At this point there is still no reference to the Greater London Council, although the GLC solicitor is available to him for assistance.)

During the review of drawings, if the construction does not comply with the by-laws (e.g., a new type of construction), the applicant can appeal to the GLC for relaxation of the requirements.

Measurements of sound insulation are not usually made to show compliance with the by-law, because the law is not framed in terms of acoustical properties. However, tests are made in response to complaints from tenants. Such investigations are rather rare.....fewer than five per year.. But each one might involve a large number of tests in different dwellings, living rooms and bedrooms separately. In the tested buildings about 10% of the rooms would be measured.

The Council usually suggests remedies in case of serious lack of sound isolation.

The Council is considering trying to include noise control requirements in the by-laws, including requirements for the building facade. That status of these plans is unknown at present.

B.6 WEST GERMANY

Information Sources:

Horst Diestel, Director, Acoustics Division, Physikalisch-Technische Bundesanstalt (PTB), (German National Bureau of Standards), Braunschweig.

Rudolf Martin, Director, Hearing Acoustics Department, PTB (German National Bureau of Standards), Braunschweig.

Paul Dämmig, Director, Room Acoustics Department, PTB, Braunschweig.

H. Schultze, Institut fur Baustoffkunde und Stahlbetonbau der Technische Universität Braunschweig, Braunschweig.

Ludwig Schreiber, Müller-BBM, Acoustical Consulting, Munich.

B.6.1 Official Documents

There is no National building code in West Germany, with noise control requirements applying throughout the country. Instead, there is a National Standard document (DIN 4109, Parts 1-5) in which quantitative standard acoustical measurement procedures are prescribed, and quantitative requirements for noise control, in terms of minimum accepatble levels of acoustical performance, are stated. The measurement procedures closely follow ISO, though until last year the rating methods differed (see Appendix A).

DIN 4109 is not an official building code, itself. But there is a committee, a part of the National German Standards Organization, called ETB (Ausschuss für Einheitliches Technische Baubestimmung) which gives recommendations (including acoustical requirements), in the form of a recommended standard building code (Muster-bauordnung), to the higher building authorities of the different German States. The different States have adopted their own building codes ("Bauordnung"), all based strongly on the ETB Standard Code but with small differences.

These codes, themselves, do not contain specific numerical requirements for noise control, but use wording like "sufficient noise insulation". For example, the Bavarian building code says "the state of the art must be applied." Concurrently, a Bavarian Ministerial Official Paper (Ministerialamtsblatt, of 7 December 1963) defines DIN 4109, Parts 2, 3 and 4 as constituting the "state of the art". Thus, those "unofficial" recommendations become requirements of the official building code including the DIN numerical requirements on noise control.

B.6.2 Status

The State laws to date apply only to multifamily dwellings (including duplexes and row houses) but not to single houses. DIN 4109, however, contains requirements applying to hospitals, schools, restaurants, offices, workshops, and stores and even (for the "higher grade" requirements) to single houses.

DIN 4109 is formally not a law but only a recommendation. In practice, however, it is stronger than a recommendation, because the requirements of DIN 4109 are forcefully applied by several official groups. Judges use those standards to base their ruling in suits or complaints by tenants concerning noisy buildings. The Federal finance ministries may indirectly require a contractor to comply with DIN 4109 recommendations, as follows: in order to get a building permit the contractor must have a check of the sound insulation. The inspector does not usually examine the drawings, but instead stamps them "Heed DIN 4109". This puts the responsibility on the builder if anything goes wrong, so he generally "heeds DIN 4109".

In fact, builders have become very conscientious about complying with the DIN recommendations and, in fact, come to the test institutes and pay for acoustical consulting advice, rather than be caught and penalized at the end of the project. They tend to feel that DIN 4109 represents "state of the art" and that it can and should be followed.

DIN 4109 includes two standards of acceptability, a minimum requirement and a recommended (improved) requirement. When the DIN standard first came out, the minimum requirement was usually aimed for; but today most builders shoot for the "improved" level of performance.

B.6.3 Summary of the Acoustical Requirements

The German Standard DIN 4109 gives recommendations for airborne and impact sound insulation for party walls and floors between dwellings. There are no requirements on the transmission loss of exterior walls nor of interior non-party walls. No explicit limits on outdoor noise are given in DIN 4109 (these are dealt with by another German law, TA-Lärm). The DIN standard does require that "quiet rooms" be located on the side of the building facing away from the street, otherwise, double windows must be provided; no numerical requirements are given, however. Quantitative limits are placed on the permissible levels of noise generated by equipment in the building: plumbing, elevators, pumps, burners for central heating, etc.

B.6.4 Enforcement

Local authorities enforce the noise control regulations via building permits: one can hardly build anything in Germany without a permit. In order to get a building permit, it is necessary to have the drawings of the building approved, as well as (for example) a structural engineer's approval of the construction for strength, a construction engineer's statement of compliance with DIN 4109, (according to approved construction examples given in DIN 4109, Part 3) and adequate thermal insulation. The authority gives the building permit only if everything is in order. If the plans do not fulfull the code requirements on noise control (and in every German State this practically means DIN 4109), approval is withheld.

If the proposed construction is not cited in DIN 4109, then a preliminary test must be made to qualify the construction, usually in a standard test laboratory. In special cases a test building may be authorized for field tests of transmission loss or impact insulation.

In Germany, there are about forty officially approved testing institutions for field testing, although only six have their own laboratory facilities. These field testing teams must go every two years to PTB in Braunschweig to demonstrate their capability. The PTB gives to ETB a list of the institutes that have qualified in these demonstrations, and ETB forwards the list to the various States, who in turn publish the list in a Ministerial Official Paper.

It was planned from time to time to publish updated lists of approved constructions from the various German States, to supplement DIN 4109, but this has not been done very effectively, so far. A new Institute in Berlin has been in existence since 1969, but not much was forthcoming, as of 1971.

The "money source" is often a local office of the finance ministry, which makes two steps mandatory:

1. A preliminary (theoretical) check of the drawings to see that the basic construction is consistent with approved constructions, according to DIN 4109. This preliminary check might be done, for example, by one of the testing institutes (or, exceptionally, by PTB). If the report submitted by the institute to the finance ministry is satisfactory, the builder gets *the first one-third* of his money for the project.

2. After completion of the building, a compliance test is made, usually of about 10% of the apartments for large projects, or a greater percentage for small projects. For these tests, "quick-check" procedures* are used to save time, involving fewer measurements

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*These methods are subject of further research (including vibration measurements on the ceiling) instead of impact noise level measurements in the receiving room.

bands, fewer microphone positions, and fewer impact machine positions than in the complete standard tests; sound absorption is measured by a steady-state method. The estimated accuracy of the quick test is about ± 1 dB, and if the results of the quick test are within 2 dB of the required performance, the test must be re-run with the full test procedure; otherwise, the quick-test data are regarded as clearly "go" or "no go". If not built with a government loan, the buildings are not tested at all. The architect may, however, ask for tests, particularly for floated floors.

For all buildings that get loans from the States, test measurements in the completed building are usually required by the authorities. The last one-third of the money is withheld until field tests show compliance with DIN 4109. Every project built with government funds gets tested, but not every building in the project. The percentage of buildings tested depends upon the local State authority, probably about 5% altogether. For example, in each 20 to 30 apartments, one transmission loss test of a wall or floor might be made. Often a "short test" with the tapping machine is cheaper, and perhaps 10 measurements would be made in a building. Evidently, there is considerable latitude in the amount of testing required.

The "short test" for impact noise consists of generating a standard noise of fixed level with a loudspeaker in the *receiving* room. This loudspeaker and the electronic generating device together comprise a constant-power source whose noise spectrum has the shape of the DIN standard reference curve for impact sound insulation rating (TSM). This standard DIN noise is measured, and then the noise generated in the receiving room by the standard tapping machine in the room above is measured, both with A-weighting. The difference in A-levels so measured is a good approximation to the Trittschallschutzmass (TSM), the single-number impact noise rating of DIN 4109. With typical German floors, the discrepancy between the results of the short test and the standard test is less than 2 dB.

About 95% or more of the apartment buildings have floated floor slabs for purely acoustical reasons (thus, radiant heating is almost never practical). Earlier constructions used glass fiber blanket or mineral wool layer for the resilient element of the floated floor. Nowadays the trend is to use soft PVC expanded granules, such as are used for packing fragile items for shipment. Coconut fiber is also used; it is very expensive but very good.

More and more apartments are sold rather than rented in Germany. The buyers may request acoustical tests before they pay the final amount, or they may require a guarantee of adequate noise insulation in the purchase contract.

What if the building fails to pass the tests? If the building was built with a government loan, the State authorities may require corrective measures if the deviations are large. If small, then the final money is given to the builder, but with the stipulation that, if the tenants complain, corrective measures will be required. If the inspector from the Building Ministry, in the final building inspection, finds something obviously wrong, he may require an immediate fix, or may force the builder to get acoustical tests and/or recommendations from a consultant.

It has been proposed that, in buildings that fail the acoustical tests by significant amounts, the owner would have to lower the rent proportionately. Practically speaking, however, adjustment of the rents would not work in Germany, in general, because of the great demand for apartments. (If a private court suit succeeds, the judgment could award reduction of the tenants' rent in poorly constructed buildings; it depends on the judge in each case).

There is a dilemma. In 1976, people are becoming much more critical, demanding good sound insulation in view of the high prices and rents that have come with inflation. But if the cost of good insulation raises the rent too much, there is trouble in renting or selling the apartment. If only a few of the units fail the test, the builder must take remedial steps to meet the DIN requirements, in order to collect the last one-third of his money from the authorities. If many of the units fail, it creates a serious problem. Several years ago, the enforcement was very strict and the last third of the construction money was, indeed, withheld. As a result, a number of builders went bankrupt. More recently, strict enforcement is made only if the tenants complain, in which case the builder would have to fix the units causing complaint. Most complaints come from buyers of duplex or row houses, NOT because the sound isolation is worse, but because the background noise is usually lower and because buyers are usually more critical than tenants.

The comparison of test results on the immediately postwar buildings of 1950 with later tests in 1968, shown in Fig. B.4, is dramatic: about 10 dB improvement, on average for the airborne sound insulation and about 20 dB for impact insulation.

No special funds are provided to cover the added cost of noise control in the building; it is simply a requirement that must be met, just like safety standards.

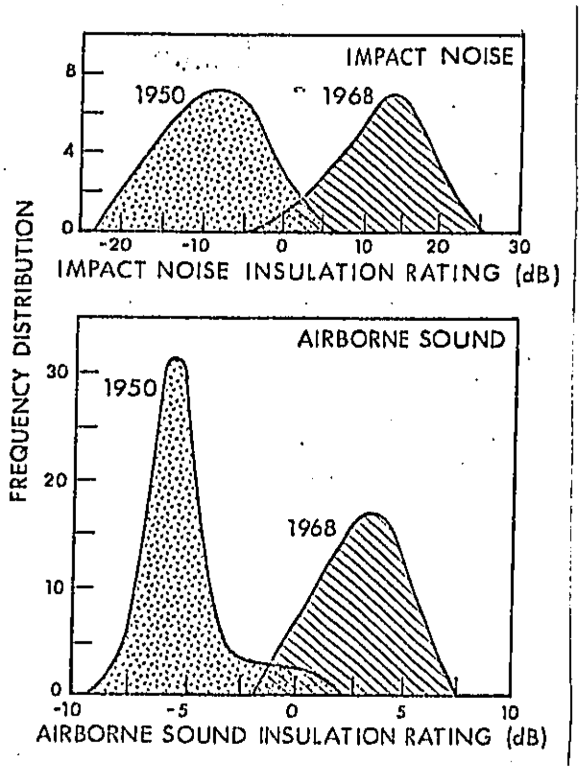

FIG. B.4. IMPROVEMENT IN ACOUSTICAL QUALITY IN MULTI-FAMILY DWELLINGS FROM 1950 TO 1968.

DRAFT

The building must come up to "state of the art" (meaning DIN 4109) and the cost of achieving this is included in the builder's request for building funds. An exception to this rule may be made in the case of a special research project or an experimental construction program: the architect might be given an extra reward for an innovative, ingenious or cheap solution.

B.6.5 Success of the Enforcement

It is said that very few of the buildings tested nowadays fail to comply with the noise requirements of DIN 4109. Although there has been no systematic study of this question at the national level, the judgment that compliance is very good is based on informal comparison of the test results from the various testing institutes, indicating that compliance is high and increasing.

This was not the case in the early 1960's as indicated by field test results in Southern Germany, shown in Figs. B.5 and B.6. (See also Figs. 6-8 of the main report). Nevertheless, steady improvement in rate of compliance is evident. Today, only about 10% of the dwellings fail the tests.

Failures are blamed on several problems: lightweight bricks used in party walls; leaks in the exterior walls; pass-through doorways used during construction not properly closed after the building is finished; short-circuited floating floors, particularly at doorways opening off of corridors.

The faults are not in the drawings (which have already been checked for suitable choice of construction in the earlier phase), but may usually be found in short-

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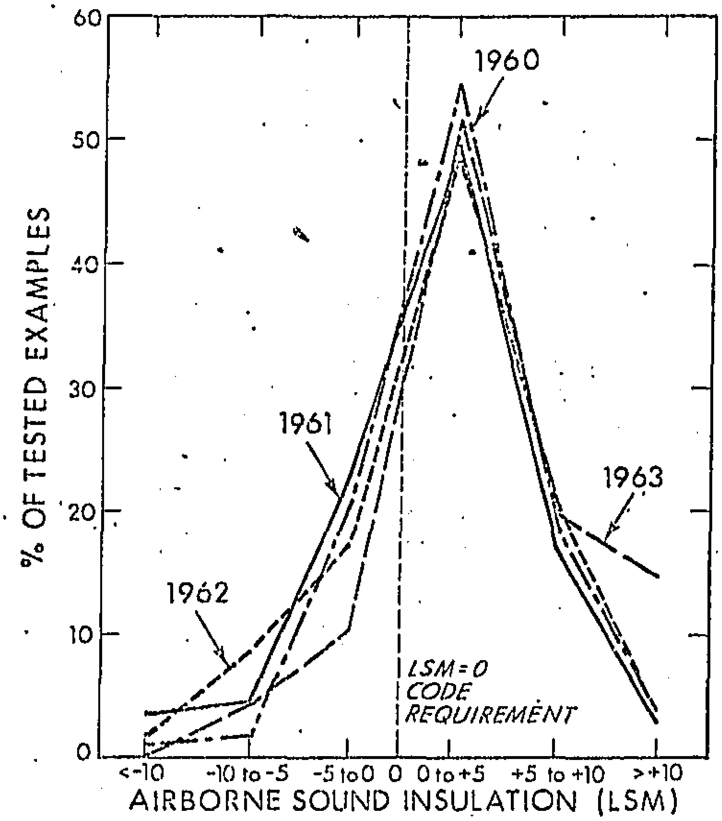

FIG. B.5. WALLS: AIRBORNE SOUND INSULATION FIELD TESTS, 1960 TO 1963, MULLER-BBN, MUNICH.

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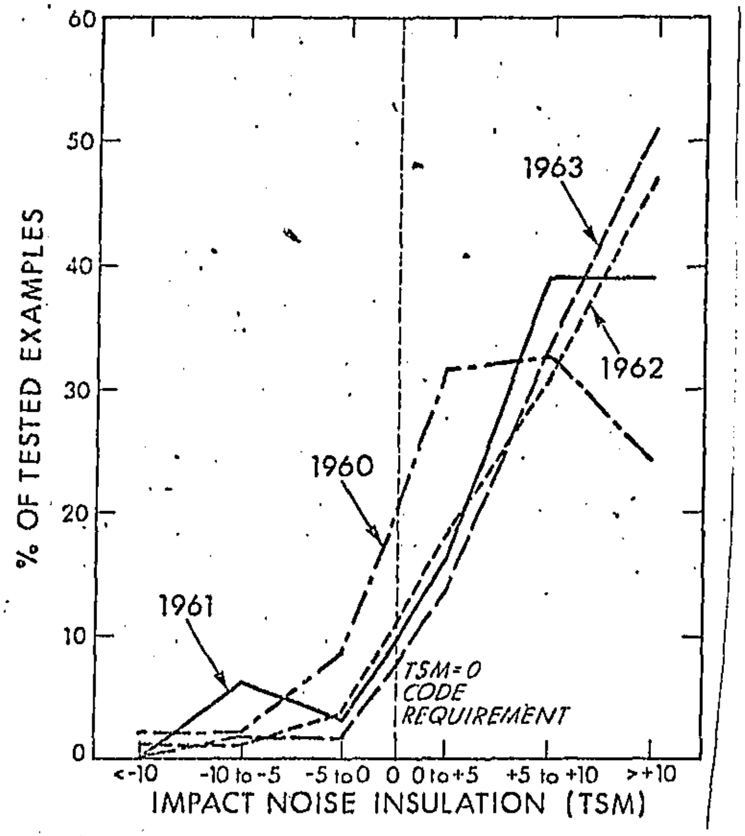

FIG. B.6. FLOORS: IMPACT NOISE INSULATION FIELD TESTS, 1960 TO 1963, MULLER-BBN, MUNICH.

circuited floating slabs, or in plumbing installations whose noise exceeds 30 dBA.

These comments above refer only to multi-family dwellings financed by the German Federal Government (and administered by the Building Section of the Finance Ministry) for certain groups of people who are eligible for such funding. This means, in practice, only 10 to 25% of all new buildings regularly exhibit the high rate of compliance with noise regulations discussed above.

Other people have no such protection, and if there are acoustical problems, they must pay to take the suit to court and to conduct acoustical tests if they want them.

Large private building companies, e.g. "Neue Heimat" belonging to the labor unions would, as a matter of course, have spot-checks made to be sure that their builders' work is up to standards.

No continuing record of test compliance and failures is compiled for presentation either to the government or the public. Some of the testing institutes publish statistics of the results of their noise tests, but not on a regular bases.

B.6.6 General Comments

It is expected that DIN 4109 will be completely rewritten, but it is not sure when, certainly not this year. Therefore, the most important changes, particularly in the tables of required acoustical performance (Part 2) will be put into operation as needed, by governmental decree, as has already been done for schools (see footnote, page).

Noise of plumbing is one of the weakest areas these days, most in need of better control. Until now, DIN 4109 has not been strictly enforced with respect to plumbing noise, which has been very annoying for the tenants, particularly because of the monolithic masonry construction typical in apartments.

In fact, a "quiet hours" requirement is often written into the standard apartment rental contract form, that forbids certain activities between 10 pm and 7 am, such as using the shower, wearing shoes, or using radio or television.

This is obviously a severe restriction on the tenants, but the problem of nighttime noise is a very difficult one. As an example, DIN 4109 is dated September 1962; it was adopted by the Bavarian State in 1963, with the nighttime noise level limited to less than 30 dBA; this could never be well controlled, however. Subsequently, the permissible level was raised to 40 dBA, but now it is back to 35 dBA maximum noise level.

The current tendency is to specify the *means* for avoiding excessive noise rather than to specify maximum noise levels.

The plumbing manufacturers want the DIN 4109 maximum permissible noise limit for building equipment raised from 30 to 35 dBA. PTB is willing to go along with this, but it wants to have two classes of quality: the minimum quality requirement would be 35 dBA, with an "improved quality" requirement of 25 dBA. Then, just as for walls and floors, in a few years everyone will shoot for the improved quality.

In fact, it is expected that in the re-write of DIN 4109, the minimum and improved requirements for walls and floors will become more strict; 5 to 8 dB reduction for impact noise, and 5 to 8 dB increase for the transmission loss* between row houses (no changes for apartments). The limits on the noise of appliances may be decreased by about 5 dB.

In further standardization work, the emphasis will be placed on the development of simpler, but still reliable, test procedures for wider and more effective enforcement of noise control in buildings. There are a number of such quick tests in practical use already, both for airborne and impact sound. During the next two years, PTB will investigate on a statistical basis the deviations to be expected between the standard and the simplified procedures, for different shapes of the curves of transmission loss and the noise reduction in the field, so that precision requirements for simplified procedures can be established.

At Gösele's Institute in Stuttgart, a procedure for measuring impact sound is under investigation that completely abandons the measurement of the impact sound levels in the receiving room, but rather is based on measurements of structureborne vibration in the floor slab. Last year, Lothar Cremer proposed (at a Congress on acoustics in Czechoslovakia; to be published in *Acustica*, December 1976) that DIN 4109 requirements on impact sound insulation be replaced by structure-borne vibration measurements. [This may be all right for the concrete slabs (with or without floating floors) that are common in Germany; it would certainly not be suitable, for example, for wood joist and timber constructions.]

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*For schools, such a change has already been recommended to the German States by the Institut für Bautechnik.

APPENDIX B -- PART II

The first part of Appendix B dealt with the enforcement practices of six European countries that have relatively active programs of enforcement of the noise control provisions in their building codes.

There are other countries that have adopted noise control recommendations or requirements relating to dwellings, but that do not necessarily enforce them very vigorously, as yet. (In some cases, the apparent lack of enforcement effort may simply reflect the fact that the results are not widely published). Nevertheless, it is of interest, for the present purpose, to see what directions their efforts have taken, as reported in this second part of Appendix B, because they have given some consideration to the problem.

B.7 AUSTRIA

The most recent document is a draft, dated April 1976, of Austrian Standard B 8115, "Schallschutz und Raumakustik im Hochbau" (Sound Insulation and Room Acoustics in Building Construction). Its predecessors were B 2115 of December 1936, B 8115 of October 1949, and B 8115 of April 1959, so it has a long history.

The 1976 draft is a comprehensive document of 35 pages, which includes not only requirements for maximum acceptable noise levels and for airborne and impact sound insulation in buildings, but also guidance of building layout and planning for protection against outdoor noise.

It covers dwellings, hotels, schools, hospitals, rest homes, and offices, and proposes two degrees of acoustical quality, one 5 dB better than the other.

The acoustical parameters to be evaluated and the ratings of airborne and impact sound insulation are virtually identical to those of West Germany, though recommendations are also made in terms of the ISO ratings, I_a and I_i. In addition, analogous ratings are formulated from measurements of the normalised level difference, D_{na}, for adjacent rooms, the "diagonal level difference" $D_n 1,3$ between nonadjacent rooms and the level difference D_s, through ventilating shafts.

Examples are given of constructions that are deemed to comply with the requirements, along with their insulation ratings.

Recommendations are given for reverberation time, not only in staircases, as in a number of other European building codes, but also in various kinds of rooms. Moreover, advice is given on desirable features of room acoustics (room geometry and absorption surfaces) to assure good hearing conditions in conference rooms, council chambers, assembly rooms, classrooms, etc.

No information is available as to the intensity or effectiveness of enforcement of the Austrian code.

B.8 BELGIUM

A current Belgian Standard [*30*], entitled "Criteria of Acoustical Isolation," dates from December 1966; it was the original edition. A draft revision dated 20 March 1975 is under consideration [*30a*].

There are, however, no Belgian prescriptions having the force of law in the field of acoustics. For the provision of adequate sound isolation in buildings, therefore, one must rely on the recommendations of the Belgian

Standard mentioned above, on the desired and recommendations of the Superior Counsel for Hygiene, and on the ISO recommendations [71].

The Counsel for Hygiene is concerned only with occupational hearing and environmental noise problems.

The Belgian Standard gives recommendations for both the transmission loss, R, of partitions, measured in the laboratory, and the normalized level difference, D_{na}, between rooms measured in the field, and for the impact noise transmission, L_{na}, for floors, all measured in 1/3-octave bands.

The recommendations are stated in terms of categories of acoustical quality, defined by a series of five reference curves for airborne sound insulation and isolation, and three for impact sound insulation. The shape of these curves is complicated and quite unlike the ISO curves. (See Figure A-6).

The quality category is assigned to a construction according to whether the measured curve is on the favorable side of a reference curve with no more than 1 dB average unfavorable deviation in *each* of three frequency ranges: low (100 - 315 Hz), medium (400 - 1250 Hz), and high (1600 - 3150 Hz).

Quality categories of acoustical performance are recommended for partitions and floors in dwellings, according to the kinds of rooms they separate: living rooms, bedrooms, kitchens, playrooms, bathrooms, staircases, elevators, and even facades. For schools, distinction is made between lecture rooms, study halls, reading rooms, music rooms, gymnasiums, and facade walls. For offices, recommendations are made for managerial staff offices, boardrooms, typing (and other mechanical) rooms, and densely populated offices.

In the recent draft revision [30a], this already complicated set of categories is further refined, such that each category now exists in two degrees of quality, one recommended for "good" acoustical quality in the situations where it is appropriate (see above), and another that is regarded as a minimum requirement, which the Housing Ministry intends to incorporate in the Building Code [70]. Just when this will occur is another question. Meanwhile, the draft document is being used by architects as a useful guide.

However, it is recognized that the mere issuance of recommendations for adequate sound isolation does not suffice to achieve the desired goal. It is necessary to know how, in practice, to realize and maintain the proposed acoustical quality. For example, choosing a partition with *transmission loss* of a certain quality category by no means assures the attainment of the same quality of noise level difference between the rooms it separates in the finished building.

The Centre Scientifique et Technique de la Construction, in Brussels, has made field measurements in buildings to evaluate the current state of sound isolation in Belgium [72]. The results indicate that quality category I is practically impossible to achieve by an means; even category II is very seldom achieved with simple walls in finished buildings. Double walls, although in theory they might achieve category II, and in fact sometimes do in laboratory tests, are always spoiled in the field by flanking transmission.

In a series of twenty measurements of airborne sound insulation, with eight different types of wall, only one test satisfied the requirements of the Standard for category II.

Faced with the necessity to conclude either that the current Belgian Standard is too strict or that the acoustical quality of Belgian housing is inadequate, it was decided (by comparison of the Belgian Standard with foreign Codes) that the latter conclusion was correct! Despite the use of traditional masonry construction, the results obtained were mediocre, or even very bad [72], because of errors in construction.

The C. S. T. C. is currently engaged in research to develop light-weight double walls that can achieve the desired sound isolation in buildings.

B.9 EAST GERMANY

The requirements for sound insulation in buildings in the German Democratic Republic (DDR) are contained in the DDR Standard TGL 10687, Part 3, in a draft of March 1969 which became effective 1 April 1971. Other parts of this Standard deal with acoustical definitions, permissible noise levels (in all kinds of locations), sound absorption, environmental noise, city planning, etc. A second DDR Standard, TGL 10688, dating from about the same time, prescribes measurement methods for a variety of acoustical tests, and specifications for test equipment, in ten parts. We are concerned here only with TGL 10687, Part 3, which has the status of national law for the sound insulation requirements in buildings.

The TGL Standards are enforced for new buildings by the Ministry of Health from their date of issue. Other laws adopt the same acoustical requirements for existing buildings.

Sound insulation requirements are prescribed for walls and floors in multifamily dwellings, apartments, hospitals, sanitariums, schools, kindergartens, hostels, hotels and guest houses, with differing requirements depending on the kinds of room (bedroom, living room, kitchen, workroom, bath, staircase, corridors, etc.). Special requirements apply for such dwellings adjacent to offices, bars, clubrooms, theaters, restaurants, and other especially noisy places. Also, special airborne sound insulation requirements for the doors in these various establishments are given. Suggestions are offered for wall and floor constructions that are deemed to comply with the requirements. Thus, the acoustical requirements are intended to apply to all places where people live, work, or play.

Note that, in East Germany, an individual can build only a single home for his own family; only the Government can build large buildings, such as apartment houses.

In East Berlin there are only two large State-owned construction companies: one concentrates on housing development, the other on offices, industrial buildings, department stores, and the like. The planning and siting for these buildings all takes place within the construction companies, and thus the whole Building Code enforcement problem is simplified.

There are special construction companies, all belonging to the State, that specialize in power plants, chemical industries, etc.

Within the Building Ministry, there is a department, Staatlicher Bauaufsicht, ("Building Police") that reviews all building drawings before construction, to assure compliance with the standards (*all* standards, including economy, fire resistance, static strength, and acoustics.... last and least!) These building police personnel have offices within the construction companies, to simplify inspection of the drawings before construction and of the buildings when they are finished.

In the post-construction inspection, if the inspector thinks there has been a mistake, he complains to his own company, which then requests a field test to determine what is wrong.

Only a few institutes are authorized to make field tests on acoustics; therefore, not a great numbef of buildings are actually tested. Many more field tests would be required to get anything like 100% fulfillment of the building code requirements.

On the other hand, in East Germany there are only about ten typical kinds of building construction. These were built and tested extensively in experimental buildings, years ago. Complete acoustical studies at that time determined virtually all of their acoustical properties and likely hazards, before they were admitted for extensive construction throughout the country. (In the experimental buildings, 20 to 50% of the rooms would be tested.)

Accordingly, only a small number of finished buildings are tested nowadays as a matter of course.

If a finished building should fail the sound insulation requirements, there would be a discussion between the inspector and the construction company, and corrections would be made IF it is economically possible. Otherwise, there would be an adjustment in the amount of rent, in the following sense. The rent is normally paid by the tenant to the Government; in case of a rent adjustment in favor of the tenant for faulty sound isolation, the difference must be made up by the (Government-owned) construction company, in a computed lump sum. Even though the construction companies are State-owned, they do earn money, some of which goes into bonuses for the workers, but some of which must be reserved for rental make-up, in case of failure to meet Code requirements.

The acoustical tests, which are usually made by the Central Building Properties Institute of the East German Building Academy, in East Berlin, must be paid for by the construction company. The cost of acoustical treatment necessary to comply with the sound insulation standards is calculated as part of the normal cost of the building.

There has been a distinct trend toward improved sound insulation since the war, as indicated in the results of about fifty test measurements per year of impact sound insulation in the period from 1960 to 1966. The number of buildings in which the floors met the requirement (E_T = + 4 dB) increased from about 30% in 1960 to 70-80% in 1965/66. In the same period, the average value of impact insulation index increased from -1 to +6 dB [73].

No systematic record of acoustical performance in buildings is kept, however, either for public or government consumption.

About 30% of the buildings tested nowadays fail to meet the acoustical requirements. This degree of compliance is regarded as relatively high; it comes about because the Government-owned construction company relies on the acoustical advice of the Bauakademie, and automatically complies with it. The main difficulties, as elsewhere, come from flanking transmission due to errors in the construction.

B.10 SWITZERLAND

The Swiss Standard SIA 181 of 15 May 1970 [27], and a draft revision dated 18 April 1972 [28] are described in Appendix A. Unfortunately, no information is available concerning the enforcement of these regulations or the success thereof.

B.11 CANADA

The National Building Code of Canada, 1970 [74], requires that "walls and floors separating dwelling units shall be designed to restrict sound transmission" in conformance with a simple requirement of STC 45 for all party partitions.

A table of acoustical performance for various constructions is stated in terms of three quality classes: I, II and III. Rating I corresponds to STC 50 and is considered good; rating II corresponds to STC 45 - 50 and is considered fair; rating III corresponds to STC less than 45 and is not acceptable for Code compliance.

No information is available as to enforcement of the Code.

B.12 UNITED STATES

The only requirements on sound insulation that apply across the entire United States are those of the Minimum

Property Standards of the Federal Housing Administration, described in Appendix A. Each of the regional FHA offices is allowed to exercise its own discretion in the enforement of these requirements, however, and there is little uniformity in enforcement across the country. In general, it can be said that the requirements are not actively enforced.

A number of other local jurisdictions have noise control requirements in their building codes, as shown in Table B.1 [see separate sheet].

Enforcement is limited to inspection of the building drawings and, according to informal reports, barely succeeds in avoiding acoustical disasters, most of the time.

"Of all the complaints owners throughout the country hear about postwar apartments, lack of sound proofing heads the list most frequently. There isn't even a close second [75]."

For more detail see Appendix G.

TABLE B.1

BUILDING CODE NOISE REQUIREMENTS IN USA: PARTY WALLS AND FLOORS

Date			
1963	FHA Minimum Property Standards	STC 40 to 55 depending on outdoor noise level and type of rooms	INR -8 to +5 depending on outdoor noise level and type of rooms
1964	Arcadia, Calif.	AVG. TL = 50 dB	Tapping loss (undefined)
1964	Monrovia, Calif.	AVG. TL $\geq$ 45 dB	None
1965	Berkeley, Calif.	STC 35 to 45 depending on rooms	None
1968	FHA FT/TS 24	STC 46 to 60	IIC 46 to 65
1970	Newark, N.J.	STC 50 (lab) STC 45 (field)	INR = 0 (IIC 52)(lab) INR = -5(IIC 47)(field)
1972	Los Angeles, Calif.	STC 50 (lab) STC 45 (field) STC 26 (corridor doors)	IIC 50 (lab) IIC 45 (field)
1972	New York City	STC 50 (lab) STC 48 (field)	INR = 0 (IIC52) (lab) INR = -2 (IIC50)(field)
1972	Uniform Building Code	STC 50 (lab) STC 45 (field) STC 30 (entrance doors)	IIC 50 (lab) IIC 45 (field)
1974	State of California	STC 50 (lab) STC 45 (field) STC 30 (corridor doors)	IIC 50 (lab) IIC 45 (field)

APPENDIX C: Questionnaire Used In Interviews Concerning European Building Codes And Noise Ordinances

A. Official Documents (Texts)

1. Building Code (get complete text)
   - a) Includes noise levels indoors? outdoors?
2. Noise Ordinance (get complete text)
3. Valid at national, state or city level?
   - a) If more than one, are they consistent? If not, which takes precedence?

B. Status

1. Law or recommendation?
2. Affects dwellings only? Multi-family or single houses?
3. Offices or other buildings?

C. Enforcement

1. Who is responsible for enforcement? Government (local or national?) Builder? Other?
2. Does financing or approval for building permit depend on review of drawings? On preliminary tests? On pilot tests of new construction types? (Lab* or field tests?)
3. Tests of completed buildings to demonstrate compliance?
   - a) What % of buildings are tested?
   - b) What % of rooms in tested buildings are tested?
4. What happens if building fails to comply with requirement?
   - a) Corrective measures?
   - b) Adjustment of rentals?
5. Is there special funding to meet the added cost of necessary acoustical treatment to meet requirement? to cover the cost of the tests to demonstrate compliance?

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*Is there a single official testing laboratory?

D. Results

1. What % of buildings tested fail to comply?
2. Is there a continuing record presented to the government or to the people to show that current buildings are complying or are otherwise shown to be satisfactory?
3. Is there a periodic summary of current status of "privacy in homes"?
4. Are there records with which to check progress, or "ups and downs" in success of noise abatement programs?

E. Off the Record

1. What discrepancies between the "official position" and the actual situation?
2. What changes are being discussed or planned?

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APPENDIX D

NORMALIZATION AND IMPACT NOISE LEVEL BANDWIDTH

This Appendix presents a brief discussion of two topics that nearly always cause confusion:

1. Normalization of the acoustic test data actually measured to a standard amount of absorption (or a standard reverberation time) in the receiving room.
2. The arbitrary practice in some countries of correcting impact noise data measured in 1/3-octave bands of frequency to levels that correspond to octave-band data.

D.1. NORMALIZATION

The amount of noise produced in the receiving room by sound generated in the source room depends not only on the acoustical insulation of the partition under test, but also on the amount of sound-absorbing material in the receiving room. If there are many carpets, draperies, upholstered chairs and the like, the sound level there will be less than if the room were bare or only sparsely furnished. Since field measurements of partitions may be made in all sorts of furnished apartments, there is a certain amount of variation in measured values, due only to differences in the amount of absorption present in each case. In order to make a fair comparison between the test data and the criterion curve, this variation must be eliminated so that all measured data are comparable. This is accomplished by correcting the raw sound pressure levels to the values that *would* have been measured with some standard condition of absorption in the receiving room. Different countries have chosen different ways in which to make this normalization: some of them, such as Sweden, Switzerland, Austria, Belgium, Germany (East and West), and U.S.A. have settled upon a standard amount of sound absorption (equal to 10 sq meters = 107.6 sq ft) in the receiving room; others, such as Norway, Denmark, Great Britain, France, The Netherlands, and Finland, normalize to a standard receiving room reverberation time of 0.5 sec. Normalization to a standard reverberation time avoids the necessity of calculating the volume of the receiving room.

It will now be shown that in rooms of ordinary size, there is little difference between these two kinds of normalization: if we let the acoustical power level radiated into the receiving room by the partition be represented by the symbol PWL_o, then the average sound pressure level (SPL) in the receiving room is given by the formula*

$$SPL = PWL_o + 10 \log \frac{4}{A} \qquad (1)$$

where A (in Sabins or sq ft) is the amount of absorption in the room.

This expression confirms the statement made above concerning the necessity to "normalize" all measured results. For constant PWL_o, as the absorption in the receiving room increases, the second term on the right decreases and the measured sound pressure level diminishes, and vice versa.

Equation (1) represents the average sound pressure level found in any room having sound absorption A, when the partition radiates a given power level, PWL_o. Now, if we denote by SPL_{A_o} the "normalized" sound pressure level that would be found in a particular room with a standard amount of absorption A_o, when the same power level PWL_o is coming through the partition, we have, analogous to equation (1):

$$SPL_{A_o} = SPL + 10 \log \frac{4}{A_o} = PWL_o + 10 \log \frac{4}{A} + 10 \log \frac{A}{A_o}$$

or, substituting from equation (1):

$$SPL_{A_o} = SPL + 10 \log \frac{A}{A_o} \quad . \qquad (2)$$

The term ($10 \log \frac{A}{A_o}$) is a correction term, which can be applied to the measured SPL in any room to obtain the SPL_{A_o} "normalized to A_o".

Equation (1) can be rewritten to illustrate normalizing to a standard reverberation time T_o. The classical Sabine

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*Adapted from Beranek, L.L., "Acoustics", McGraw-Hill, New York (1954), p. 315, equation (10.64).

formula for the reverberation time of a room in terms of its volume (in cu ft) and the sound absorption A (in Sabins or sq ft) in the room is*

$$T = \frac{0.049\ V}{A} \quad . \tag{3}$$

If we substitute A from equation (3) into equation (1) we get:

$$\text{SPL} = \text{PWL}_o + 10 \log \frac{4}{A} = \text{PWL}_o + 10 \log \frac{4\ T}{0.049\ V} \quad . \tag{4}$$

For a standard reverberation time T_o, the normalized sound pressure level (still for the same amount of power radiated into the room) is

$$\text{SPL}_{T_o} = \text{PWL}_o + 10 \log \frac{4T_o}{0.049\ V} = \text{PWL}_o + 10 \log \frac{4\ T}{0.049\ V} + 10 \log \frac{T_o}{T} \quad .$$

or, substituting from equation (4)

$$\text{SPL}_{T_o} = \text{SPL} + 10 \log \frac{T_o}{T} \quad . \tag{5}$$

Now ($10 \log \frac{T_o}{T}$) is a correction term which can be applied to the measured SPL in any room to obtain the SPL_{T_o} "normalized to T_o".

We now establish the relation between SPL_{A_o} and SPL_{T_o} by rewriting equation (5), then adding and subtracting the quantity $10 \log \frac{A}{A_o}$:

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*The English system is used throughout; the standard absorption of A_o = 10 sq. m. is converted to sq ft for use in formulas; we use the "10 sq.m." because of the consistency of the literature on this point.

$$SPL_{T_o} = SPL + 10 \log \frac{T_o}{T} + 10 \log \frac{A}{A_o} - 10 \log \frac{A}{A_o}$$

$$= \underbrace{SPL + 10 \log \frac{A}{A_o}}_{SPL_{A_o}} - 10 \log \frac{TA}{T_o A_o} \quad .$$

But from equation (2), $SPL + 10 \log \frac{A}{A_o} = SPL_{A_o}$ and from equation (3), $TA = 0.049\ V$, so:

$$SPL_{T_o} = SPL_{A_o} - 10 \log \frac{0.049\ V}{T_o\ A_o} \quad . \qquad (6)$$

Substituting the standard values of T_o and A_o used in the European codes, $T_o = 0.5$ sec and $A_o = 10$ sq.m. (=107.6 sq ft) and rearranging, we finally have the desired relation between the sound pressure levels, normalized in both ways:

$$SPL_{A_o} - SPL_{T_o} = 10 \log \frac{V}{1100} \quad . \qquad (7)$$

From this equation, we can find the size of room in which the two kinds of normalization are exactly equivalent, by setting $SPL_{A_o} = SPL_{T_o}$. This requires that $10 \log \frac{V}{1100} = 0$, or $\frac{V}{1100} = 1$. The tw8 normalizations give the same numerical result if the receiving room volume is V = 1100 cu ft. The mean dimension of such a room is 10.32 ft, and this is an ordinary size.

In a room of volume *greater* than this, the very same measured sound pressure level, when normalized to A_o = 10 sq.m. (as in Sweden, USA and Germany), will yield a higher number than if normalized to T_o = 0.5 sec (as in Denmark, Great Britain, Norway, Finland, France), by an amount equal to ($10 \log \frac{V}{1100}$) decibels.

Therefore, in comparing the codes of Sweden, Switzerland, Austria, Belgium, and Germany with the Danish, Dutch, Norwegian and French codes, the former are seen to be relatively *more* severe by this amount for rooms larger than 1100 cu ft, and *less* severe for smaller rooms.

The amount of the difference is shown in Fig. D.1. For the typical range of room volumes encountered in multifamily dwellings, this difference ranges from -1.5 to +2.8 dB, a variation no greater than the uncertainty of typical field measurements. Therefore, for the purposes of this report, we have made no attempt to convert all code requirements and measurements to one system of normalization (which would be impossible anyway, since the field-test receiving-room volumes were not always given in the published data) but have treated all data as equivalent and comparable, whichever normalization was used.

D.2 CONFUSION OF IMPACT NOISE LEVELS VS BANDWIDTH

The reader must be warned that throughout the literature on impact noise there runs a confusion which traces back to an unusual and illogical convention that, nevertheless, is firmly based in the history of the subject.

In the early days, the electrical filters available for analyzing the sound into different frequency bands were octave-band filters; these filters separated the audible spectrum into eight bands, each of them one octave in width. "Octave-band sound pressure levels," corresponding to the acoustical energy present in each band, were reported and plotted at the center frequency of these octave bands in order to display the frequency spectrum of the sound as a curve of sound pressure level vs frequency.

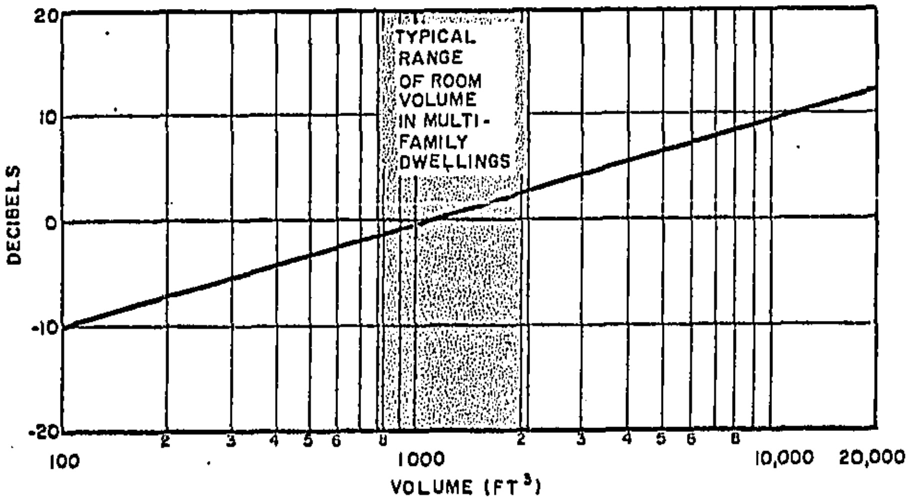

FIG. D.1. COMPARISON OF TWO KINDS OF NORMALIZATION.

In a room of volume V, the same measured value of sound pressure level when normalized to a room absorption, A_0, of 10 m^2 (as in the German and Swedish codes) will exceed the value normalized to a standard reverberation time, T, of 0.5 sec (as in the British, Danish, Norwegian, and Finnish codes) by an amount shown on the ordinate scale. For a room volume of 1100 ft^3 the normalized sound pressure level is the same by both methods no matter how much absorption is in the receiving room. For (larger) volumes, the
(smaller)
Swedith and German codes would be relatively (more)
(less)
severe than the others.

In later years, filters were developed which broke the frequency spectrum down into 1/3-octave bands, thus permitting a more refined analysis of the spectrum. It is implicit in this process that only one-third as much energy is passed through a 1/3-octave band filter as through an octave band filter centered on the same frequency. As a result, a spectrum analyzed into 1/3-octave bands results in a lower curve than one broken up into octave bands.

This is illustrated in Fig. D.2. Meter #1 will read for frequencies near f_o a sound energy three times greater than Meter #2, because the octave-band filter passes three times as much energy at frequencies near f_o as does the 1/3-octave band filter. But note that the 1/3-octave band analysis procedure will record in that same octave band two more readings (for frequencies near f_1 and f_2). Therefore, three values are determined within the band where the octave-band analysis plots only one; the sum of the energies in these three 1/3-octave bands, of course, adds up to the same amount of energy as registered by the octave-band system. This three-fold difference of energy between the two systems is equivalent to a difference of five decibels in sound pressure level. Typical results of octave band and 1/3-octave band analysis are shown *for the same noise* in Fig. D.3; note that the reading in each 1/3-octave band is about 5 dB (a factor of 3) lower, but there are three times as many bands.

So far, the discussion is generally valid for all kinds of broadband noise. There is no problem with measurements of airborne sound insulation, because the same bandwidth is always used for both source and receiving room test data, and the 5 dB discrepancy cancels out in forming the level difference.

The difficulties arise with measurements of impact noise insulation. No matter how a given spectrum of impact noise has been analyzed, its level at each frequency

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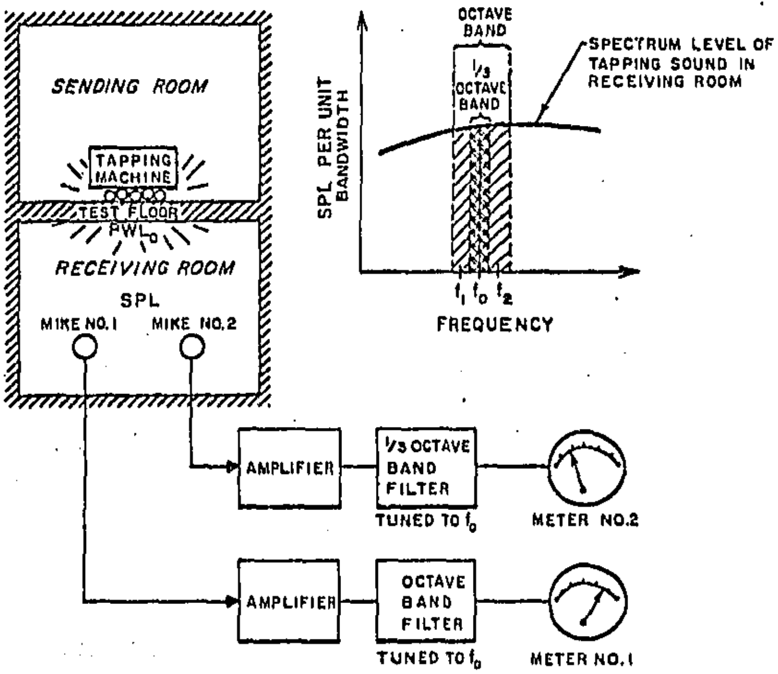

FIG. D.2. COMPARISON OF IMPACT NOISE MEASUREMENTS IN OCTAVE BANDS AND 1/3-OCTAVE BANDS.

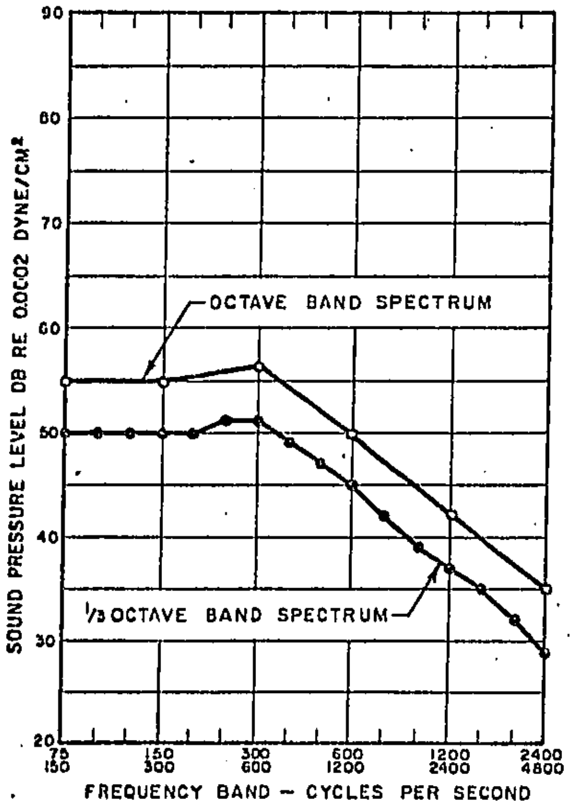

FIG. D.3. COMPARISON OF THE SAME NOISE, AS MEASURED IN OCTAVE BANDS AND 1/3-OCTAVE BANDS.

is supposed to be checked for compliance against a criterion curve which (as a matter of history in most countries) is expressed in terms of octave band levels. The possibility for confusion in the literature arises from differing efforts to deal with this requirement. In order to make the 1/3-octave-band spectrum of impact noise of a test floor comparable with the earlier octave-band spectra, it was agreed conventionally to correct all 1/3-octave-band analyses by adding five decibels at each frequency, so that (for example, in Fig. D.3) the two spectrum curves would lie roughly on top of each other; then both curves can be directly compared with the octave band criterion curve.

This arbitrary convention results in a contradictory situation where two spectra, one plotted at octave-band center frequencies with octave-band levels, and the other plotted at 1/3-octave-band frequencies but corrected (by adding 5 dB) to octave-band levels, even though they represent exactly the same sound, do not, when added up, agree in the total amount of energy represented. The 1/3-octave band spectrum adds up to an overall level that is 5 dB higher than the overall level derived from the octave-band spectrum of the same impact sound.

Moreover, the confusion is compounded because not all of the countries have adopted the same convention. Some countries* plot impact spectra with octave-band levels at octave-band frequencies; some** with octave-band levels at 1/3-octave-band frequencies, according to the convention, just described, of arbitrarily adding 5 decibels to the

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* e.g., the Dutch and sometimes the British.

** e.g., the Germans (East and West), the British, the Austrians, the Belgians, the Swiss, and the National Bureau of Standards in the U.S.A.

measured 1/3-octave band levels; but others*** plot 1/3-octave-band levels at 1/3-octave-band frequencies without making the arbitrary correction.

One must be very cautious in reading the literature to be sure at all times exactly which convention is being followed in reporting (or specifying requirements for) impact noise levels.

*** e.g., the Swedish, the Danish, the French, the Finnish, and the Norwegians.

APPENDIX E

"Sound Isolation Requirements Between Buildings"

Ove Brandt

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Sound Insulation Requirements between Dwellings

by Ove Brandt

In a number of countries it has, during more than the past two decades, become necessary to introduce acoustic insulation specifications for flatted dwellings. The reasons for this are several. One is that modern flats get poor insulation if such directives are not enforced one way or another. In many countries flats are no longer built the traditional way with thick and heavy floors and walls but instead they are erected by modern prefab methods which usually imply reduced mass and thickness for the sound insulating barriers between the flats. Even then a good insulation may be obtained but only by a very careful planning of the buildings. However, many building designers have little or no acoustic training to solve this problem and it is simply ignored in most cases if no acoustic requirements exist.

It is not necessary to remind the readers that the number and power of acoustic sources in flats have grown tremendously also and thus stress the need for insulation between neighbours.

We do not expect this problem to be taken so seriously in countries where most people live in their own house. But in England where only 5% of dwellings were built as flats between the two great wars, acoustic recommendations were issued during the 1950-ies nevertheless and they seem to be developing into strict requirements in Scotland where a tradition for living in flats exists. Such is also the case in the colder climates of Scandinavia—it is not at all surprising that Sweden where 73% of the dwellings produced are flats (1961) was among the first countries to introduce insulation requirements.

If we do not want our cities to grow enormously we simply have to build flats in place of houses. But people will not want to remain in their flats if we do not solve the sound insulation problem.

For such reasons and others acoustic specifications have now been introduced in at least 13 countries. I shall try to review the international situation within this field.

Do the insulation requirements give us enough protection?

When the first proposals for acoustic requirements were made in Germany in 1938 (1) little was known as to how much insulation is required between two flats. Our theoretical and experimental knowledge was to a great extent limited to laboratory conditions for partitions and floors. It became necessary to estimate what was required.

As to *airborne sound* the choice fell on the insulation equivalent to that provided by a 25 cm plastered brickwall. Thus, the first requirements were expressed as minimum average figures principally based on laboratory measurements on this brickwall. The frequency range chosen was nearly the same as we have today: 100-3000 Hz. In Scandinavia the same estimation was also made and the same expressions used when requirements were introduced here shortly after the war.

However, the brickwall was often replaced by other types of partitions, very often lightweight double walls in lighter prefabricated buildings. It was then easy to get a very high average figure, especially if it was measured in a laboratory with good craftmanship and no flanking transmission. But, the result in the field as experienced by the tenant was not judged to be equally good. It was thought necessary to express the required insulation not as an average figure for the whole frequency range but as a curve, based on octave or $^1/_3$-octave intervals, a *grading curve*. Thus constructions with a high average insulation based on the insulation curve of the double wall as in fig. 1 would not be permitted. Also the realities of field conditions were taken care of in introducing requirements based on field results and intended for field control.

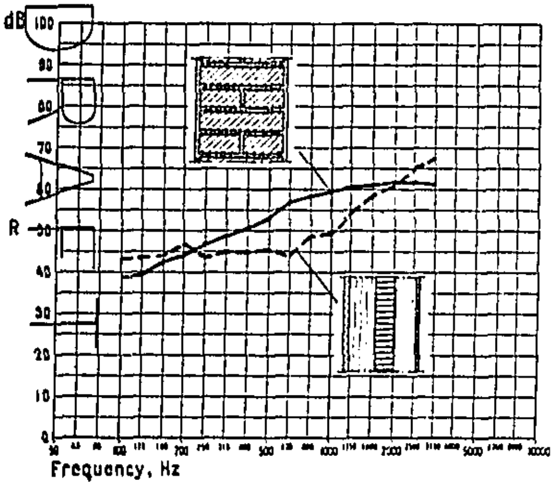

Fig. 1. Airborne sound insulation of a 25 cm plastered brickwall ($\bar{R}$ = 52 dB) and a double wall consisting of two leaves of 8 cm plastered stone and Rockwool ($\bar{R}$ = 50 dB).

In Germany, a new single figure, *the Schallschutzmass*, was proposed to replace the average arithmetical figure(2). For airborne sound, the figure Luftschallschutzmass (LSM) was based on the proposed grading curves: it is the number of dB's that a measured curve has to be lifted or lowered in order to satisfy the required grading curve. LSM becomes 0 if the requirement is exactly satisfied, has positive and rising figures for accepted insulation curves but negative for insulation below the grading curve. Similar figures were proposed for the impact sound insulation, Trittschallschutzmass (TSM).

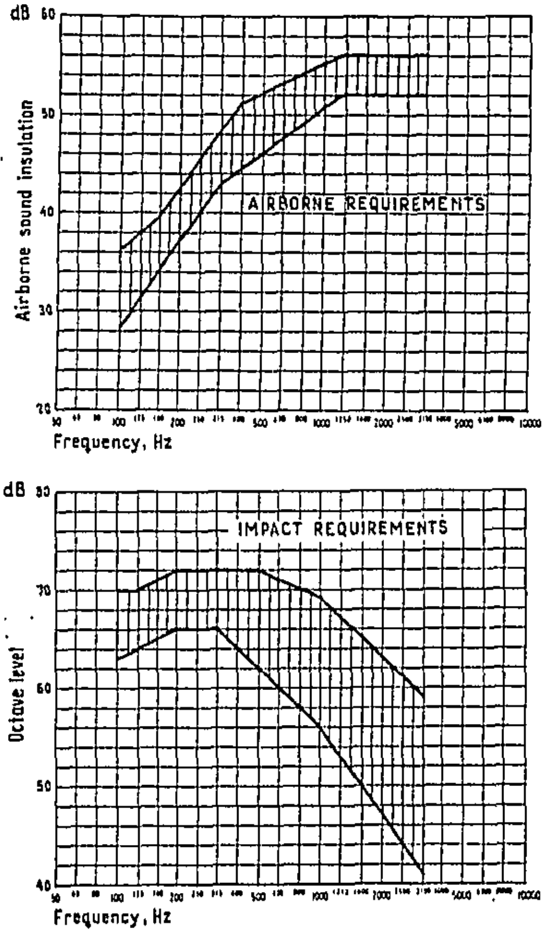

Fig. 2. Present grading curves for airborne sound (A) differ less than the curves for impact sound (B).

Even with these refinements, the background was still the same assumption that the 25 cm brickwall had sufficient insulation. The grading curve, first introduced in Germany after the war, was based on a number of laboratory and field measurements on this type of wall. However, with changing building technique towards prefabs in some countries one might ask why the insulation provided by this brickwall should be a divine answer to the need for acoustic protection as interpreted in the laboratory as well as in the actual buildings in the form as average figure and as minimum curve with the correct value at all frequency bands.
We have had a similar development for the requirements on impact sound insulation. However, in this case different countries have apparently not had a common construction to suppose was adequate as with the brickwall for airborne insulation. It seems that in each country a choice has been made between current floor constructions and the better of them have become the standard and this has lead to a much greater spread in requirements for impact insulation compared with airborne insulation, fig. 2. So even more for impact insulation the question may be raised: "Which is the "right" answer for adequate protection against impact noises?"
The direct method to find out an answer to these questions is simply to ask people living in flats what they think about the acoustic insulation against the noise in the other flats and then make an objective measurement of the insulation in order to find out what the answer means in dB-requirements. It sounds very easy, but in fact it is not the easiest way to do it. The need for acoustic insulation may vary much from family to family. Some families produce a lot af sound with radios, TV:s, children and many more sources and do not care much about the noise they may hear from the neighbours in pauses between their own noises, and they may be honestly surprised if they get noise complaints from their neighbours. Some families may be at the other extreme: producing very little sound themselves and thus creating no masking to the neighbours' noises which may upset them very much and perhaps disturb rest and sleep thereby leading to strong complaints about the insulation. Of great importance is also the outside background noise level, with traffic as the main source: a high level leads to masking of the interior noises and thus an impression that the sound insulation is good.
For these and many more reasons it is of no use to make such a survey on a little scale if anything useful shall be concluded. The survey must comprise several hundreds of flats, carefully selected to give a typical picture of the numerous variations in the human reaction and activity and the objective sound insulation. In practice it is not really possible to get enough material to answer all the questions one might like to have answered.
Such social surveys have been carried out in England, Holland, Norway and Sweden (3, 4, 5, 6, 7). The English surveys shall be briefly reviewed. In a flat survey the material was divided in 3 groups of flats with a difference in floor insulation of roughly 5 dB between each group, but having the same insulation in the horizontal direction. In a similar survey for row houses the material was divided in 2 groups, one having an average airborne insulation between neighbouring houses of 50 dB, the other with an insulation of 55 dB. These dwellings were all chosen amongst local authority houses or flats which, as I understand, means that they are built in an economic way in order that people with a low income can afford to live there. The results are therefore, as pointed out by the investigators, not necessarily valid for other sorts of dwellings with higher rent and standard.

In the *row houses* only the airborne sound insulation in the horizontal direction was n
ured. The two groups, comprising 250 pairs of houses, each had, as mentioned, an ave
insulation of 50 and 55 dB, for a single, plastered 25 cm brickwall and for a double wa
two leaves of 11 cm brick and an airspace of 5 cm, respectively. The insulation cu
reported from field measurements on these two walls are given on fig. 3. It was found
there was no distinguishable difference in the disturbance in the two groups of houses
the difference in insulation is found primarily at high frequencies it was concluded

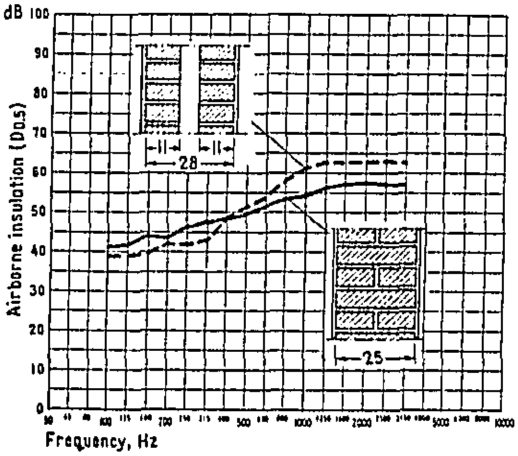

Fig. 3. Airborne insulation (D
for the English party walls in
social survey. Average of twe
one 23 cm solid brick walls
five 27 cm cavity brick wall
houses.

better high-frequency insulation, obtained with a double wall, gives no appreciable adv
tage for the tenants. This is explained by the fact that it is the low and medium frequen
that are heard through walls as such frequency components dominate in the source which
verified by other investigations.
These results were ready at about the same time as the first grading curves, still based on t
insulation of the 25 cm brickwall, were proposed in Germany. As the same type of w
was concluded to be sufficient for row houses in England, even here a grading curve w
used based also on the brickwall. The two grading curves do not agree very well as se
from fig. 4.
The English social surveys in *flats* comprised 3 groups of about 1500 flats arranged accor
ing to different floor insulations for both airborne and impact sound. As mentioned befo
the average floor insulation differed 5 dB between each of the 3 groups while the horizont
airborne insulation was equivalent to a 25 cm plastered brickwall, i.e. roughly 50 dB
average. Group I had an average airborne insulation of 49 dB, Group II 44 and Group I
39 dB. Insulation curves for the Group I-III floors are given in fig. 5. The difference b

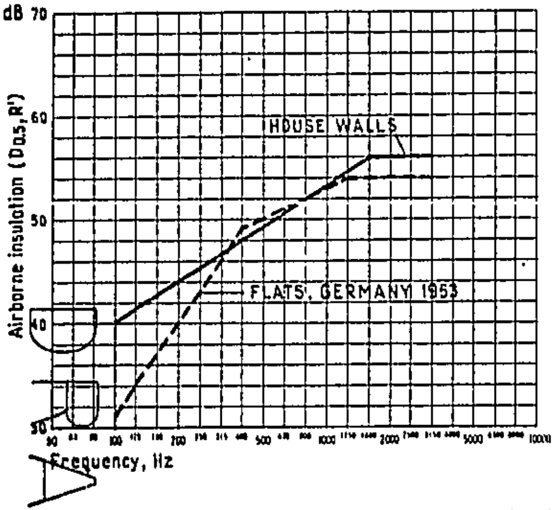

Fig. 4. The English row house recommendation and the original German requirement (1953), both based on the brickwall insulation do not coincide.

tween these insulation Groups is so big that one expects a clear indication of annoyance, least in Group I. The results of the survey did also verify this expectation for the Groups I and II: In the first Group 22% said they were disturbed by the noise, in the second Group the number of disturbed increased to 36%. In Group III this number surprisingly decreased to 21%. This unexpected relative satisfaction with acoustic insulation was explained by the fact that the tenants in Group III previously had had very bad dwellings and still seemed to compare the present improved conditions with their preceding living conditions.

In Group I noise from the neighbouring flats was no more annoying than so much else attached to living in a flat—as mentioned before England is not a country where it is considered a natural thing to live in a flat in place of a traditional house. In Group II flats noise was one of the biggest disturbances. Another measure for these Groups is that in Group I only 7% did not complain of anything, while this figure in Group II increased to 14%, and in the immune Group III these uncomplaining people were no less than 42%. This last Group was not used as a basis for recommendation as its tenants were uncritical in general. It was concluded from this survey that the insulation obtained with the floors in Group I flats should be used as a minimum recommendation for flatted dwellings, as these tenants apparently equally complained about noise as so much else in the flats. The average insulation curve was somewhat simplified, fig. 6, and was called Grade I.

A grade II was defined as a 6 dB lower curve at all frequencies. It was stated when employing this Grade that the tenants must be expected to find their neighbours noise the worst thing to endure in the flats.

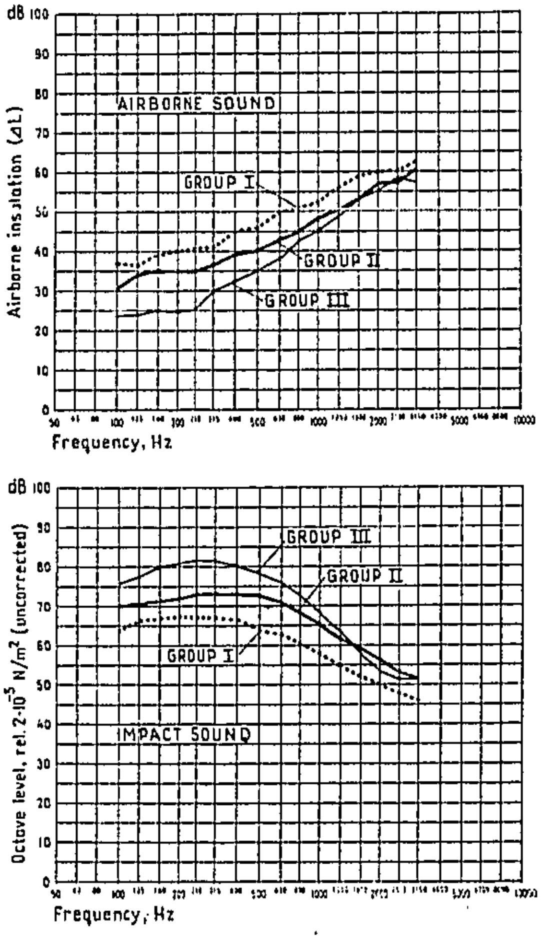

Fig. 5. Measured values fo airborne and impact sound i the English flat survey. Th values are average figures and uncorrected.

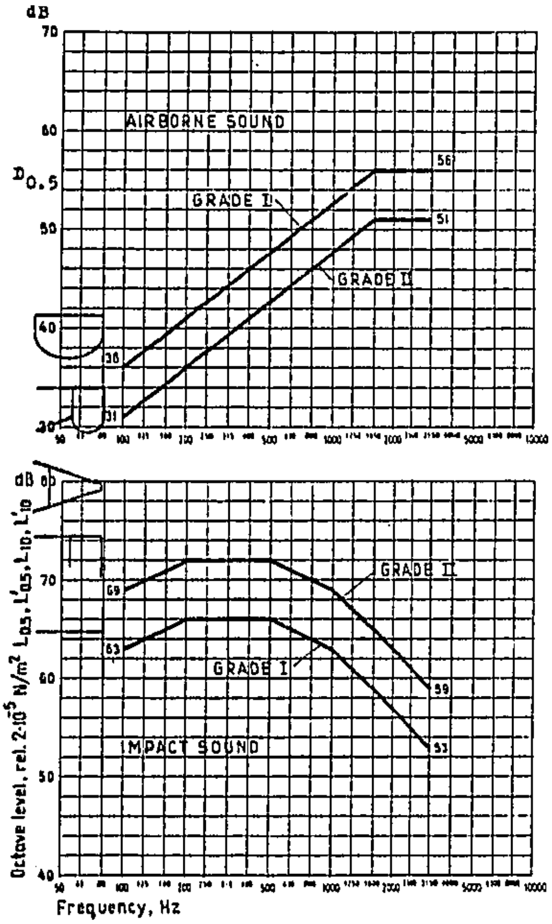

Fig. 6. From the English flat survey the conclusion was to use two grading curves for airborne and impact insulation.

It must be recalled when using Grade I for planning a block of flats that noise then is considered equally bad as draught, dampness, faults in the heating system etc. If we get rid of such shortcomings—which must be quite easy in a modern flat—one must expect that the complaints against the sound insulation increase. Also it should be remembered that this Group of flats was taken amongst local authority flats with, perhaps, relatively uncritical tenants. It must finally be remembered that flats are not the traditional type of dwellings for an Englishman and he may not complain so much because he considers his flat as only a provisional state before finding his definite dwelling in a house. Apparently, the Grade I recommendation cannot be expected to give a very good acoustic protection for the tenants. A few results from the Swedish survey complete this picture. It was carried out in about 500 flats at about the same time independantly of the British surveys. As a criterion for the airborne insulation the average figure in the range 100–3200 Hz was used, which is possible because very few of the walls or floors showed anomalies in the insulation curves as they were heavy, single leaf constructions. It was found that amongst people in flats with an average airborne insulation of about 45 dB 21% were disturbed by the neighbours airborne sounds. For flats with an insulation of 48–50 dB—roughly equivalent to the 25 cm brickwall—16% expressed dissatisfaction with the airborne insulation. At the highest insulation, 50–55 dB, only 7% were disturbed by these sources.

From these surveys we see that a decent protection is gained against airborne noise with the traditional brickwall, but we can hardly expect that this standard of protection is to be considered sufficient when the general standard of flats is raised. This is especially the case in countries where the flatted dwellings tend to dominate and people do not consider a flat as a provisional place to live. Also the noise sources seem to increase in number and power and this increases the need for airborne insulation.

Most specifications for noise protection are now expressed as a grading curve. As stated before a grading curve based on the measured insulation for a 25 cm plastered brickwall is not necessarily the correct answer at all frequencies, even if such an assumption may serve us well for a provisional standard. To find out what is the correct curve is, however, not easy. It can hardly be done with the same sort of social surveys as the ones mentioned, be-

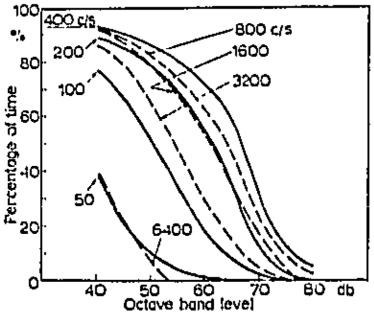

Fig. 7. Statistics of peak levels in radio-programmes. For each of eight octave bands the percentage of the time that certain octave band levels are surpassed is indicated. Based on about 55 hours of mixed radio-programmes (v. den Eijk).

cause we then need a very big material and we should have to ask people about frequency distribution etc. in terms that they are not familiar with. Other methods must be found. One method has been used by v. den Eijk in Holland. (8) He uses the fact that radio and TV-sets are the most annoying noise sources in flats and in order to find out how much insulation is needed he makes field studies on the time and frequency distribution of radio sounds in the source room in dwellings. He presents the results of such studies of 17 mornings and afternoons in fig. 7. Then he requires the level in the receiving room to be 0 phon

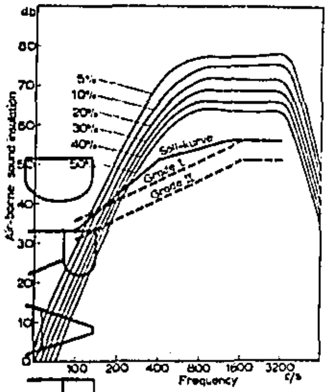

Fig. 8. Required airborne sound insulation based on a disturbing neighbour's radio level surpassing 0 phons during, in the mean, 5, 10, 20, 30, 40 or 50 per cent of the time. For comparison the German (Soll-Kurve) and the British (Grade I and II) requirements for dwellings are added (v. den Eijk).

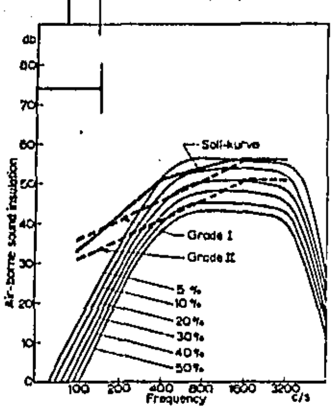

Fig. 9. Required airborne sound insulation based on a disturbing neighbour's radio level surpassing 20 phones during, in the mean, 5, 10, 20, 30, 40 or 50 per cent of the time. For comparison the German (Soll-Kurve) and the British (Grade I and II) requirements for dwellings are added (v. den Eijk).

using the Fletcher-Munson 0-phon contures for pure tones. In this way he can get the shape of required level difference. As this requirement is very high he gets curves that lie very much higher than the present grading curves in Germany and Great Britain, fig. 8. He finds it more realistic to ask for a reduction to the 20 phon-contours. This leads to required level differences which by comparison with the German grading curve can be reached with the traditional brickwall, fig. 9. As normal insulation curves are less steep below 400 Hz and usually increase above this frequency he raises the question if there is any need to have requirements outside the important frequency range 400–800 Hz. Fasold, Germany, gets similar results. (9)

The correct shape of the grading curves have also been studied by Rademacher and Venzke, Germany. (10) They simulate the insulation curves of the walls with electric filters and arrange a receiving room similar to a normal dwelling room in volume and acoustics. The observers enter this room one by one and listen to different complex sounds from loudspeakers, filtered through the "wall" filters, and compare the loudness with a third-octave band of random noise centered around 1000 Hz. The selected source sounds are male and female speech, music and random noise of different band widths—all with little dynamics to make it easier for the observers to compare with the 1000 Hz random noise.
With this technique they demonstrate how different insulation curves influence the loudness of typical sounds in a receiving room. For each type of sound they ask the observers to compare the loudness of the sound filtered through different wall filters. The results of these subjective judgements are then compared with different objective figures such as the average arithmetical insulation and different German Luftschallschutzmass based on a number of grading curves, including the one in use and others proposed in Germany. They find that quite different grading curves can be used as a basis for the Schutzmass without appreciably changing this objective measure compared with the subjective one based on loudness. Even the average figure seems to follow the subjective measure surprisingly well, fig. 10. This fact is further studied and seems to be explained by the phenomena that two frequency ranges with good and bad insulation can compensate each other. This is further studied with the wallfilters as examplified in fig. 11. The higher insulation of K at medium

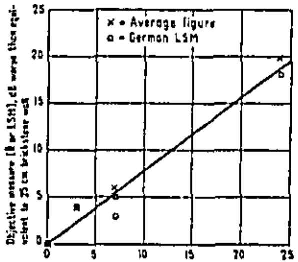

Fig. 10. Example from Rademacher and Ventze's work (10). For taped music, listeners have judged the equal loudness (phones) of this sound which they listened to "behind" different walls, evaluated by the average figure $\bar{R}$ or the Luftschallschutzmass LSM. All results are reduced to the case of 25 cm brickwall (0 dB and 0 phone).

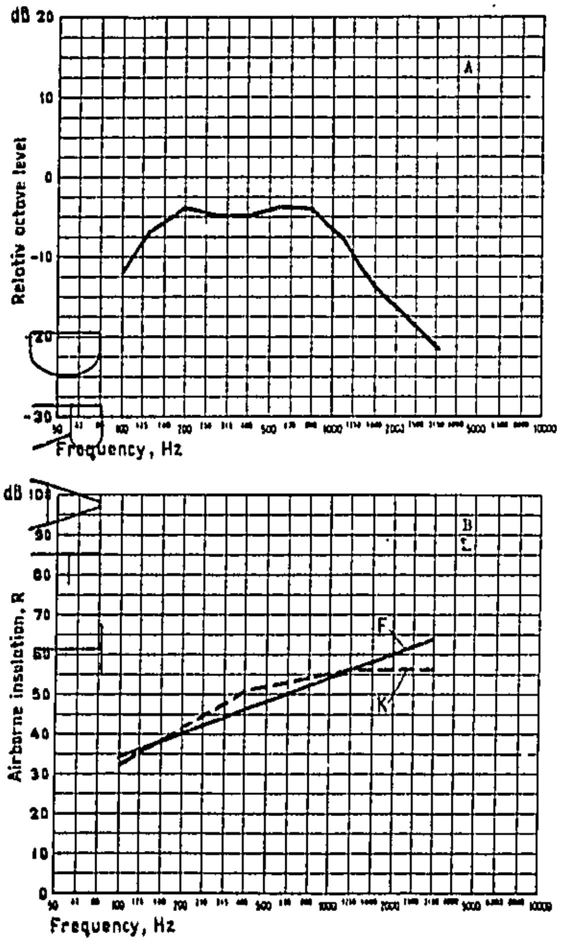

Fig. 11. When the observers listened to "coloured" noise, see A, through the wall filters with the responses F (6 dB/octave) and K, see B, it was judged to be equally loud. The average figure $\bar{R}$ and Luftschallschutzmass LSM are for F: $\bar{R}$ = 49 dB, LMS = 0 dB, for K: $\bar{R}$ = 50 dB and LMS = 2 dB.

frequencies seems to be compensated by the better insulation of F at frequencies abov 1600 Hz so that the two loudnesses are alike. This result is most interesting as the mai objections against the classical average figure have been its unrealisticly high values fo steep insulation curves. It must be remembered that these results have been obtained according to loudness levels judged at 20-30 dB higher levels in the receiving room compare with what is usually experienced in a dwelling room. When one is exposed to the sound i a building some of the frequency range of the neighbours sound may be masked by th background noise and we do not know the distribution in time and frequency of thi masking noise.

That the background noise must be very important for the judgement of the interio insulation is demonstrated for instance in the Swedish social survey mentioned above. Her the flats were put into 3 groups according to the exposure to outdoor noise—the noise wa characterized as 1) high level, 2) normal town level and 3) low or very low noise level. Th tenants who said they were annoyed by the outdoor noise were 19, 13 and 6% for th Groups 1)-3) respectively. When they were asked about the annoyance caused by nois from other flats the percentage disturbed were 26, 42 and 50% for the same 3 groups 1)-3) a very clear indication of the influence of the outdoor noise on the subjective experience o indoor insulation.

As to *impact sound insulation* our knowledge is so far quite limited. From the English surveys in flats we could draw some conclusions which lead to Grade I and II with similar remarks as for airborne sound insulation. It was also concluded that the light wooden floors had not sufficient impact insulation, even if Group III was not aware of insulations defects. As a matter of fact, in England it was recommended to use floating, concrete floors in order to satisfy Grade I, even if usually a floating floor well done should give more insulation than the required curve. From the Dutch survey we can conclude that the light floors and especially the light wooden floors are not usually sufficient for impact insulation. Finally the Swedish survey indicates that impact sounds do not seem to be a big problem if we use solid concrete floors. For tenants with floors without a separate screeding course only 7% were disturbed by impact sounds. This percentage fell to 2% for floors with a floating course on a mineral wool mat. Remembering that in the same survey the percentage of people who were annoyed by airborne sounds was 16—when airborne insulation requirements were just satisfied—one must conclude that impact sound insulation is not a big problem if the floors are not expecially light as e.g. wooden floors. This is perhaps also the explanation why grading curves for impact insulation in different countries vary so much.

It thus seems that the present requirements give us a moderate protection against the neighbours' noise, at least for airborne noise: probably some more insulation is required, especially at the low and medium frequencies, but investigations made on the frequency response have used loudness and not annoyance as a subjective criterion for sound insulation. Further masking has not been considered. We have little evidence about how closely the present grading curves must be followed before the tenants are aware of such a change. Grading curves can hardly be taken as more than a rough indication as to what sort of insulation curves we want. It is probably too early to establish new single figures based on such grading curves as they may have to be changed as new research results appear.

How is „sound insulation" defined?

As mentioned before the first insulation specifications grew out of studies in traditional transmission laboratories where only the direct sound reduction factor for a test panel is measured. For such tests we have a very reliable measuring method which we have agreed upon in the International Standardization Organization. (15) We determine the airborne sound reduction factor R in measuring the level difference ΔL between two neighbouring rooms divided by the test panel of area S the absorption A in the receiving room and thus get R from the formula:

$$R = \Delta L - 10 \log A/S \text{ dB}$$

This formula is valid if all sound in the receiving room is transmitted through the test panel. Also, diffuse fields are required in the rooms. Such conditions are not difficult to satisfy in a stationary laboratory. But we want to make the specifications in building codes valid also for the field. If we could only test or check in the laboratories rules would be of little value and certainly not gain much respect in practice.

But can we expect to have enough diffuse sound fields in normal dwelling rooms, furnished or unfurnished to make sensitive measurements? Can we use the same relationship between level-~~difference~~ and the reduction factor as is used in the laboratory according to the formula above? Or do we have more practical relationships to base our requirements on?

As a matter of fact, it is easier to make reliable measurements in dwelling rooms than one might expect. Of course we do have some troubles at very low frequencies when the room dimensions are of about the same size as the wavelength. Usually not more in a furnished room ~~than~~ in a smaller laboratory as we get some diffusion from the furniture. At higher frequencies we expect to get difficulties as the porous damping of the higher frequencies tend to make the field look like a free field in place of a diffuse field. Gösele (12) in Germany has, however, shown, that we do measure one or two dB higher levels in the pressure field in the receiving room, but if we correct to a constant absorption we get too low values for the absorption determined from the Sabine formula and from short reverberation times, which ~~compensates~~ for the error in the level measurements. He showed that by changing the reverberation time in the receiving room from less than 0.5 seconds to more than 3 seconds the corrected impact sound level changed less than 2 dB at the individual frequencies for the same floor.

In one sense there is a great difference between the laboratory and field conditions: we cannot guarantee that the sound in the receiving room has arrived only through the partition or the floor in the building. Rather it is so, that a good deal is transmitted through flanking elements, *flanking transmission.* Of course, we can still use the same formula above, but then we must include the flanking transmitted sound in the reduction factor (which is then nominated R') if we still take S as the area of the common surface for source and receiving room. This method is used with success in e.g. the German requirements and its advantage lies in its simplicity for the building designers as we shall see.

In some other building codes the level difference is used as a measure for sound insulation in a dwelling, but this magnitude must be normalized in one way or another. If we only used the level difference in a requirement, sound insulation would depend on the acoustics of the receiving room. If we increase the amount of absorption we get an apparent increase of the sound insulation observed in the diffuse field of the receiving room. We then have the possibility to correct to a certain time of reverberation or to an absorption of the dwelling room. What is to be preferred?

In order to answer this question some reverberation measurements have been made in e.g. England and Denmark. (13) It might be expected that the reverberation time increases with the room volume as we know is the case for classical concert rooms. This is also the case for unfurnished rooms and for rooms with little furniture, but not for furnished rooms. For living-rooms Larris found that the reverberation time varied only between 0.35 and 0.7 seconds with an average value around 0.5 seconds when the room volume varied from 19 to 118 m^3, fig. 12. For the same furnished rooms the absorption computed from Sabine's formula varied from 6.5 to 38 m^2. This is explained by the fact that the principal absorption

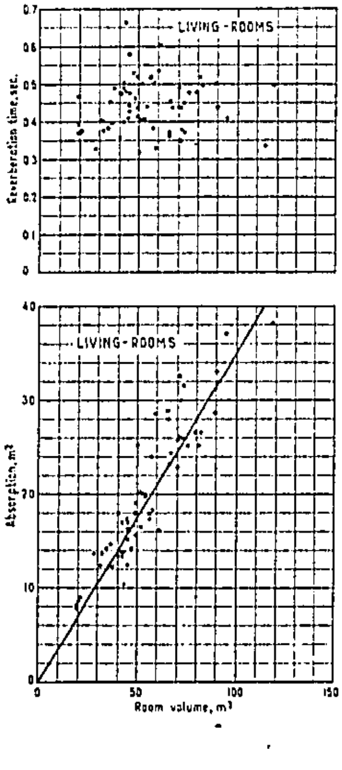

Fig. 12. Reverberation time and absorption in furnished living-rooms. Average values for 125—4000 Hz (Larris).

in living-rooms such as stuffed furniture and mats is connected with the floor. When the floor area increases with the volume the absorption must also increase and thus it is easy to show for a rather constant density of furniture the reverberation time must be quite constant. This is less true in bed-rooms where the total furniture is more constant, fig. 13. The frequency dependance has a peak in the mean frequency range, as the low frequency absorption is procured by panel absorbents and the high frequency absorption by porous absorbents.

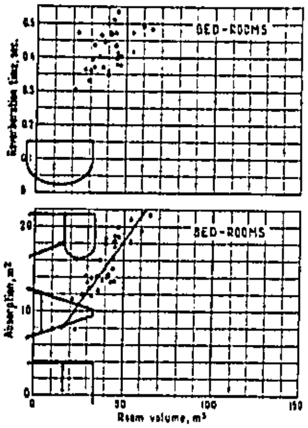

Fig. 13. Reverberation time and absorption in furnished bed-rooms. Average values for 125—4000 Hz (Larris).

If we state that a dwelling room has a reverberation time of 0.5 seconds we must have in mind that this is primarily so for living-rooms, less for bed-rooms—which in some countries tend to disappear in smaller flats—and it is not the case for rooms like kitchens, bath-rooms, halls and similar rooms with little or no furniture where we expect the reverberation time to increase with the volume.

The fact that the reverberation time in a furnished living-room is nearly constant independant of volume has lead some countries to use the level difference normalized to the reverberation time of 0.5 seconds as a basis for insulation specifications. Thus this required level difference $D_{0,5}$ is defined as:

$$D_{0,5} = \Delta L + 10 \log T/0.5 \text{ dB}$$

In this way the required level difference and also the measured one is a true picture of the observed level difference when having a living-room as a receiving room, a very important practical case in flats.

This normalized level difference is then a result of the reduction factor R' of the common surface S between two neighbouring rooms and the flanking transmitted sound from othe surfaces. This is quite easy to understand for building planners without acoustic training but it is in practice not always so easy to evaluate, not even when flanking transmission ca be neglected. The fact is that $D_{0,5}$ also depends on the volume V of the receiving roon which we see in expressing $D_{0,5}$ as a function of R':

$$D_{0,5} = R' + 10 \log \left(\frac{0.32 \,.\, V}{S}\right) \text{dB}$$

It will be noticed that this measure is not reciprocal if used between two rooms with differen volumes; the building designer may suspect that sound insulation of a structure is no reciprocal. So the direction of the measured level difference must be stated in the reports If we choose to normalize to a constant absorption we do not get this drawback. Thi measure D_{10} which has been standardized by ISO for field measurements is then defined as

$$D_{10} = \Delta L - 10 \log A/10 \text{ dB}$$

thus normalizing the level difference to a reference absorption in the receiving room o 10 m². If we express this measure by R' and the common surface of two neighbourin rooms we get:

$$D_{10} = R' + 10 \log 10/S \text{ dB}$$

leaving to the building planner to make his calculations based upon the insulation R' with or without flanking transmission and the size S of the transmitting element.

Of course also this definition has its drawbacks. For instance, for big rooms separated by big surface areas this correction gives a false picture of the real insulation when the rooms are normally furnished. We correct then to a much smaller absorption and neglect that the real absorption is bigger. When we use the same value of D_{10} for all room sizes in dwellings —which we must for the sake of simplicity—the requirements tend to be too rigourous for big rooms and perhaps too mild for small rooms. The trend should of course be in the opposite direction.

Both $D_{0,5}$ and D_{10} are of course a little difficult to handle for the architect or builder with little acoustic training. To simplify this planning it may be better to specify permitted partitions, floors etc. in the building codes, completely omitting acoustic specifications. The drawback of this method is that it may put a brake on the development of building constructions and in many cases it is difficult to give information of all the permitted combinations of e.g. partitions and joining elements. What is usually preferred is *both* an acoustic requirement somehow in dB *and* a number of examples demonstrating how to satisfy the requirements.

Some countries have like Germany preferred to simplify the specifications and also the planning by using the same reduction factor as in the laboratory, here nominated by R'. The planner then need pay no attention to variations in wall surface or room volume, but can simply refer to measuring reports from the identical constructions, even combined with the right joining constructions. Then the requirements must be adjusted to cover even big surfaces. One of the only drawbacks of this principle is that it cannot be used for cases where a common surface S between two rooms are not defined, e.g. between a living-room and a staircase. It may also be a bit disturbing to attribute all defects of for instance a bad outer wall to the common surface *S*. In Germany laboratories have been built to measure *R'* for rooms with flanking walls but still referring to a constant area of the partition, here much better insulated than the flanking construction.

The three existing definitions on airborne sound insulation, *R'*, D_{10} and $D_{0\cdot5}$, may lead to quite different results when the same figures are required as some examples will show.

If we require D_{10} and *R'* to be equally big for the same case the wall surface must be 10 m².

If we even demand D_{10} to equalize $D_{0,5}$ for horizontal insulation the volume of the receiving room must be 31.3 m³. For a room height of 2.5 m we thus get a standard receiving room with the dimensions 4 × 3.1 × 2.5 m³, which is quite a normal room in a modern flat. But quite big deviations from these dimensions may occur.

If we look at quite a big room with the floor size of 8.0 × 3.1 m² and standard height of 2.5 m, we get the following differences (vertical insulation):

$$D_{0,5} - R' = 6 \text{ dB}$$
$$D_{10} - R' = 3 \text{ dB}$$
$$D_{10} - D_{0,5} = 9 \text{ dB}$$

If we turn to small rooms the differences are usually not quite as big. A minimum standard floor for a Scandinavian bed-room is about 2.1 × 3.3 m². With the room height of 2.5 m and vertical transmission we get:

$$D_{0,5} - R' = 0.25 \text{ dB}$$
$$D_{10} - R' = 2.8 \text{ dB}$$
$$D_{0,5} - D_{10} = 2.5 \text{ dB}$$

For *impact sound transmission* we have luckily only two alternatives for definitions. One of these is to refer the measured level in the receiving room to 0.5 seconds for the same reason as for airborne insulation. This leads to the definition:

$$L_{0,5} = L + 10 \log 0.5/T \text{ dB}$$

Unlike $D_{0,5}$ we have no such drawback as lack of reciprocity because the direction of transmission is given.

The other alternative which is recommended by ISO for field and laboratory measurements is to correct to 10 m² of absorption:

$$L_{10} = L + 10 \log A/10 \text{ dB}$$

Both these alternatives have the drawback that we get a higher figure for decreasing insulation, but this disadvantage does not seem to bother building planners so much as they apparently quickly get used to it.

Obviously, we get cases when these two definitions give different figures, even if the difference is not so big as for the measures for airborne sound. Still we get the same figure if the room volume is 31.3 m³ which means a floor size of 12.5 m² for the room height of 2.5 m. A great majority of modern flats have floor sizes of this order. If the floor increases to 25 m² the difference is 3 dB. A small room has the size of about 6 m² which still gives us a difference of about 3 dB.

It is easy to show that a correction to a constant absorption is the same thing as to assume a constant power from the ceiling independently of its size. Thus we should get the same results for the same floor construction even if we measure on different floor areas. This seems to be the case for floor sizes in the range from 6–25 m² according to German [14] (Gösele) and Swedish measurements. Thus L_{10} would seem to be a good physical magnitude, but with corrections not fitted for the normal acoustics in living-rooms as for D_{10}.

We can also show that the correction to a constant time of reverberation as for $D_{0,5}$ is the same as to assume a radiated power from the ceiling growing with its surface. This measure then has the advantage to follow the variation in room volume as is done in furnished rooms but it has as mentioned its physical disadvantages.

Obviously, the three definitions for airborne sound insulations and the two for impact sound have its advantages and disadvantages and it is a matter of taste which is to be preferred. However, it should be a step forward if we could agree internationally on this subject in order to reduce confusion.

Insulation requirements or recommendations in different countries

In the preceding sections we have looked a little at the present background and terminology for insulation requirement. Let us now look at some of the principles used in different countries for acoustic specifications. A detailed report is being prepared by ISO.

In some countries such *specifications* are presented as *requirements*, in others as *recommendations*. There may be little difference in practice. The recommendations *may* have much stronger power than strict requirements which may be only writting table products completely ignored by building designers. The advantage with recommendations is that the real acoustic claim may be expressed without too much compromize with other factors from the very start. An example of this is the British Grade I recommendation for impact noise which is based on floating floors. In Austria a 5 dB higher Luftschallschutzmass (based on the German Sollkurve) is recommended. Germany gives us a good example with requirements which work well and many stationary and mobile labs are available to control the results in practice. In such a case the specifications must be somewhat milder and roughly be intended to cut off the extremely bad cases. The danger in this system is that the standards must be compromised and consequently are only partly sufficient in the majority of cases. Building planners may easily get the impression that all is well if they build just to satisfy the requirements. In fact, it might be better to have a minimum requirement combined with an uncompromised recommendation but this leads to complicated specifications without the simplicity which must characterize rules for building planners with little acoustic training.

Today at least 13 countries have insulation specifications for dwellings. In the great majority grading curves are used to express the minimum values. For airborne sound 10 countries use one of the curves presented in fig. 14 and 15.

To evaluate a measured curve in relation to a grading curve many countries follow the German system of computing the average negative deviations in the whole frequency range and setting positive deviations equal to 0. In Germany this average deviation must not exceed 2.0 dB, based on third-octave frequencies, while e.g. USSR, Bulgaria and

Czeckoslovakia base this average deviation on octave frequencies and add the rule that no single negative deviation may exceed 8 dB. In Great Britain and Scandinavia this procedure is somewhat simplified as only the sum of negative deviations is computed and not permitted to exceed 16 dB.

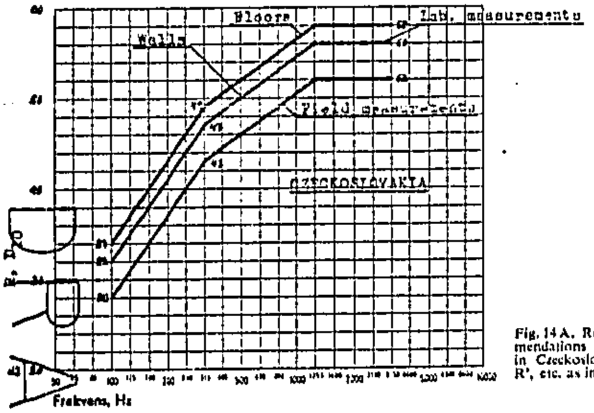

Fig. 14 A. Requirements and recommendations for airborne insulation in Czeckoslovakia. Symbols for R, R', etc. as in the preceeding section.

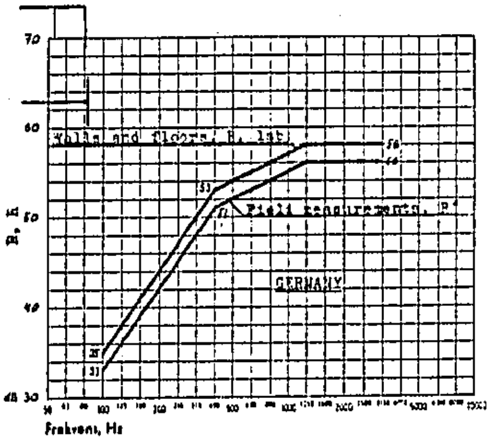

Fig. 14 B. Requirements and recommendations for airborne insulation in Germany. Symbols for R, R', etc. as in the preceeding section.

The present grading curves for impact insulation are presented in fig. 16 and the measured impact insulation should result in a curve *below* the grading curve. We have similar rules as for airborne insulation to decide on cases where part of the measured curve lies above the grading curve. The same 10 countries that have grading curves for airborne sound have such curves for impact sound transmission.

In Canada which was one of the first countries to introduce insulation specifications fo airborne sound the average minimum figure of 45 dB has been recommended for th

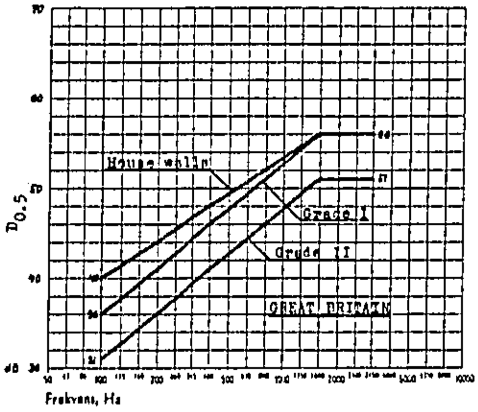

Fig. 14 C. Requirements and recommendations for airborne insulation in Great Britain. Symbols for R, R', etc. as in the preceeding section.

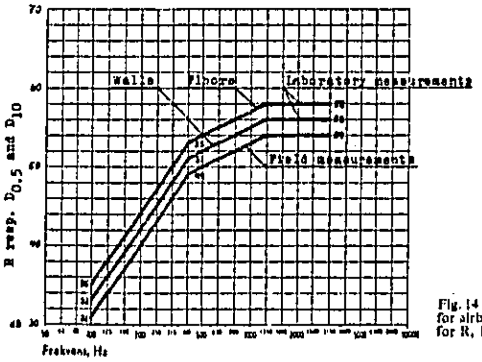

Fig. 14 D. Requirements and recommendations for airborne insulation in Scandinavia. Symbols for R, R', etc. as in the preceeding section.

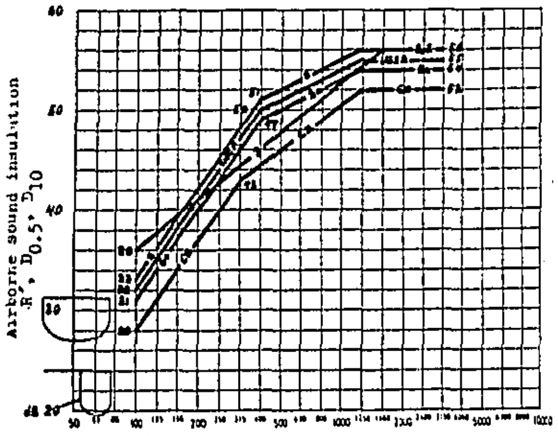

Fig. 15. Airborne sound insulation. Comparison between field requirements for flats.
1 – United Kingdom, grade I ($D_{0.5}$)
S – Germany, Sollkurve (R')
USSR – USSR, curve I (R', D_{10} (?))
Sc – Scandinavian field requirement(D_{10} in Sweden, $D_{0.5}$ in the rest of Scandinavia)
Cz – Czeckoslovakian field requirement (D_{10}).

frequency range of 125–4000 Hz; now a grading curve is being prepared. In France, average figures for airborne and impact sounds are given for the frequency ranges 100-320, 400-1250 and 1600-3200 Hz. This is a very simple principle without troublesome evaluations. Nor does it pretend to more knowledge than we possess.

In some countries, e.g. Scandinavia and France, the specifications comprise both the reduction factor for the bounderies between flats as measured in a traditional laboratory and the normalized level difference in the completed building. This complication is made because one could reach a sufficiently high level difference even if a very small element in the partition has a very low reduction factor. However, if for instance a bed is placed close to such an element very low insulation is experienced.

Some effort has so far been made to get a quality figure for insulation to replace the traditional average insulation. A few countries have followed the German example to introduce a Schallschutzmass for airborne (LSM) and impact (TSM) sound. As mentioned before it is based on the grading curves and is defined as the number of dB's that a measured curve has to be lifted or lowered in order that it can be considered acceptable (average deviation 2.0 dB). The drawback for such a single figure is primarily that it is tied to a certain curve. If this is changed we get new quality figures which must be very confusing for building designers. This is the primary reason why some countries like Scandinavia and England have hesitated to introduce another single figure for sound insulation before we have got an international agreement on such requirements. In the meantime only the sum of deviations from the grading curve is used as a provisional quality figure but with the drawback that it gives the figure 0 for all cases that we get an insulation higher than required.

A grading curve may be difficult to change when finally it has become well established in a national building code. In place one can use two (like e.g. Great Britain) or more grading curves and require an appropriate curve to be satisfied in the specific case. But it is also possible to have only one curve (like e.g. Germany, for walls) and then require different Schallschutzmasses for different situations which is the same thing as choosing between a great number of parallel grading curves.

In view of these facts one might raise the question whether it is possible to establish some sort of international standardization on sound insulation requirements, a great advantage in the growing international exchange of knowledge and products. One might well be a little pessimistic as to the success of such a work considering the different grading curves already established. Further, we can hardly as acousticians expect to change building traditions in some countries which happen to accept for instance floors with low insulation and have no apparent tenants' reaction. Obviously, other countries with building technique which happens to favour sound insulation—or have strong public opinion on this subject—would not be ready to accept an international standard so compromised. Nevertheless I have some hope for such an attempt at international cooperation on this problem.

This feeling of optimism is supported by the success of a Scandinavian collaboration on this subject. We met five years ago to agree just on the measuring methods, but found it possible also to agree on requirements. These were then shaped as the grading curves shown in fig. 14 and 16. As to airborne sound our first proposal was a grading curve a little different from the British Grade I and the German Sollkurve. However, we found it wrong to introduce another curve and thus increase the international confusion. In place we accepted the German Sollkurve for airborne sound.

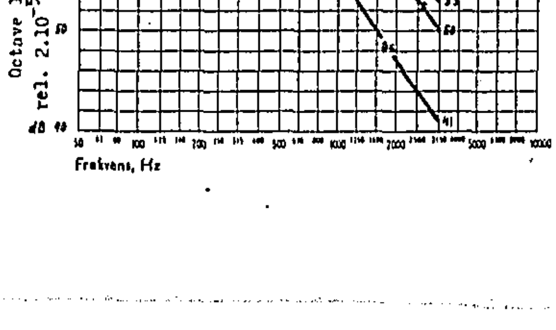

Fig. 16. Impact sound transmission. Comparison between requirements for flats.
I – United Kingdom, grade I ($L'_{0.5}$)
II – United Kingdom, grade II ($L'_{0.5}$)
S – Germany (Sollkurve) and USSR (curve IV) (L_{10}, L'_{10})
Sc – Scandinavia ($L_{0.5}$ and $L'_{0.5}$ except for Sweden where L_{10} and L'_{10} is used).

As we know the existing grading curves lead to very little change in tenants' reaction it should be possible to agree on an international grading curve, at least as a first step for airborne insulation. Also the present French method of having a number of average figures for part bands should be discussed because of its simplicity and leading to no new single figures. Also the appropriate definitions for sound insulation should be discussed and decided on.

While we discuss and perhaps accept such an international provisional recommendation we should organize more research on this subject to see how well the different systems function and also if it is possible to simplify—for instance in limiting the frequency range as suggested by v. den Eijk and others. Such an international discussion which already has started within ISO may also be a great help in countries where such specifications are not yet considered but probably needed.

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APPENDIX F

"How Noise Creeps Past the Building Codes"

Theodore J. Schultz

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How noise creeps past the building codes

Each requirement alone may seem adequate but why do rooms turn out noisy when alas, the building is complete? Measurement of structural parts, contends **Theodore J. Schultz**, ignores the building as a system. He proposes a measurement strategy for predicting isolation between two spaces.

No longer is it a novelty for a city's building code to contain requirements or recommendations for noise control; many cities in the United States and in Europe already have such regulations. But the city where these requirements are consistently enforced and also are effective in achieving their goal of adeqate privacy between dwellings still is rare, indeed. This almost uniform failure to achieve acoustical privacy, even when considerable effort has been expended, is sufficient evidence that noise control presents formidable practical difficulties.

Noise control requirements in building codes have little chance of success unless the primary objective for privacy is stated in terms of a performance specification. Compliance must be demonstrated by tests of adequate isolation in the completed building. A new approach to noise control in building codes will be proposed here that is expected to combine the advantages of existing codes and the (so far untried) requirements in terms of performance specifications. But first let us examine the pitfalls of approaches that presently are expected to do the task.

Complicated sound transmission

Sound travels from one room to another in a complicated way. Not only does it follow the primary path through the partition that separates the two rooms, but usually travels a number of other paths, some of which may be just as important, or more so, than the primary path (see Fig. 1).

A structure designed to provide privacy for the occupants of neighboring rooms requires adequate attenuation in all the possible paths by which sound from one room may reach the other. Therefore, it is not enough for an architect simply to search through a collection of transmission loss data to choose a suitable party wall with which to separate the dwellings. He must consider all the other possible sound paths as well.

For the same reasons, it is not enough for a building code to specify the Sound Transmission Class (STC) of the party wall or floor structure (this is the U.S. equivalent to the ISO's I_a rating; the definitions are almost identical, see Refs. 3 and 10) whether measured in the laboratory or in the completed building; the other sound paths may be of equal importance in assuring privacy for the tenants.

Unfortunately, the existing codes in America go this far and no farther; when it is time for the building permit to be signed, the architect's drawings are examined to see whether he has chosen constructions known from experience to provide reasonably good sound attenuation. If so, the permit is issued, the building is built and that is the end of the matter. In some cases advice is offered on how to avoid flanking transmission, but there is no inspection of the completed building to see how it all worked out. The same is true in much of Europe, except that investigations are usually made of noise intrusion complaints. In case of really serious failure, however, people hardly know what to do. Once the building is completed, no one would suggest that it be torn down and rebuilt just because it fails to provide adequate privacy.

Yet, building after building actually fails to provide privacy because the building code requirements are applied at the wrong time. It does no good to argue that the basic construction was suitable, as approved in the drawings, if, in fact, one can easily hear through the walls of the finished building. This is as foolish as trying to excuse a bad soufflé on the grounds that the eggs were of top quality! In the final analysis, what actually matters is the overall acoustical privacy achieved between the rooms in question when the building is finished. A building code that fails to face that fact directly is not likely to have much effect.

Building codes need to specify at least the acoustical isolation that must be achieved to afford adequate privacy for the tenants. Fortunately, this is the easiest thing to measure about acoustics in a building, despite a poor start in this respect.

Insulation vs. isolation achieved

In discussing methods to provide adequate acoustical privacy in multifamily dwellings, it is essential that we distinguish sharply between the *insulation properties* of a partition and the *isolation achieved* between rooms, For example, Transmission Loss[11] (TL), Sound Transmission Class[11] (STC), Sound Reduction Index[4] (R), and Airborne Sound Insulation Index[10] (I_a) all refer to the insulation property of a single partition. Noise Reduction[11] (NR) and Normalized Level Difference[4] D_n, refer to isolation between rooms. This distinction is carefully made in the ASTM Definitions[11], but it is sometimes overlooked in discussions, even among acousticians who should know better.

A recent technical paper[15] recommends a procedure that measures (with A-level differences) the isolation between rooms, but recommends the test result as an approximation to the Sound Transmission Class (presumably of the party wall, although this point was never made explicit). The dismaying fact is that the paper attracted favorable, even enthusiastic, response from the readers, who are apparently willing to accept considerable compromise in the name of simplicity.

It is not surprising that the existing building code requirements exhibit a strange assortment of errors. Some codes hope that by requiring the party wall to have a specified Sound Transmission Class, as measured in the laboratory, there will be adequate isolation between the rooms in the finished building. Others specify field performance in terms of a required field STC for the party wall, an approach which, though legitimate as far as it goes, still does not face up to the possibility of flanking paths not involving the party wall at all. Such a test doesn't evaluate the isolation between the rooms, but measures only the insulation of one of the possible sound paths.

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It appe[illegible] acousticians in the United St[illegible] and in Europe have developed and presented their test standards to architects in the wrong order. Logically, instead of developing transmission loss measurement procedures for use in laboratories and adaptable to field use, we first should have developed, emphasized and implemented the concept of privacy or isolation between rooms in finished buildings. This is what tenants really care about and what building codes really should stipulate. The basic acoustical test in a building should relate to privacy, because this is the true goal.

If a performance test of adequate privacy in the completed building reveals that the measured isolation between two dwellings falls short of what is desired (or specified), it then becomes a question of deciding which of the possible paths of sound—that is, which part of the building structure—is at fault. At this point we must use the more complicated procedures of the Field Transmission Loss Standard Test (ASTM-E336)[9] to evaluate the attenuation of each path until we find the villain; in each case we would have to show by means of ASTM's special "anti-flanking test" that our data actually correspond to the sound path under test. This procedure, related to the performance of specific individual building components, is obviously too complicated to be carried out by building code enforcement officers or, as a routine test, by anybody.

The field transmission loss test is not related to the primary goal of privacy; it is a detective tool related to the means of achieving privacy: adequate attenuation in each individual sound path. Transmission loss tests have no place in building codes, except for determining what is at fault when the building has failed the code's test of proper isolation.

Today we already have our laboratory[8] and field transmission loss[9] measurement standards and we are trying to develop a practical and effective standard test procedure for evaluating isolation achieved between rooms in completed dwellings, as contrasted with evaluating the performance of building components.

Comparing rating and test procedures

A number of rating quantities have been proposed in the past for use in building codes. In reviewing these now, keep in mind the two conflicting needs for enforcement of building code noise requirements: the test procedure must be as simple as possible with a minimum of required equipment, but the test results must be reliable enough to face legal challenge if necessary, once the building inspector has relied on the test to certify the building for occupancy or, even more crucial, if he has denied such certification.

Here, then are the quantities at issue:

Quantity:
Laboratory Transmission Loss (ASTM E90[8]) or Sound Reduction Index, R(ISO R140[4]) of a partition:

Definition:
$TL = \bar{L}_1 - \bar{L}_2 + 10 \log (S/A_2)$

Comments:
OB or 1/3 OB
No flanking is possible because of the laboratory facility construction

Quantity:
Field Transmission Loss, FTL (ASTM E336[9]) of a partition:

Definition:
$FTL = L_1 - L_2 + 10 \log (S/A_2)$

Comments:
With special test in each case to demonstrate absence of flanking transmission: OB or 1/3 OB

Both of the transmission loss tests (laboratory and field) focus on the *type* of wall or floor structure, because the size of the wall and the properties of the receiving room are normalized out in the "10 log (S/A)" term. The transmission loss tests have no meaning unless there is a complete party wall (or floor) com-

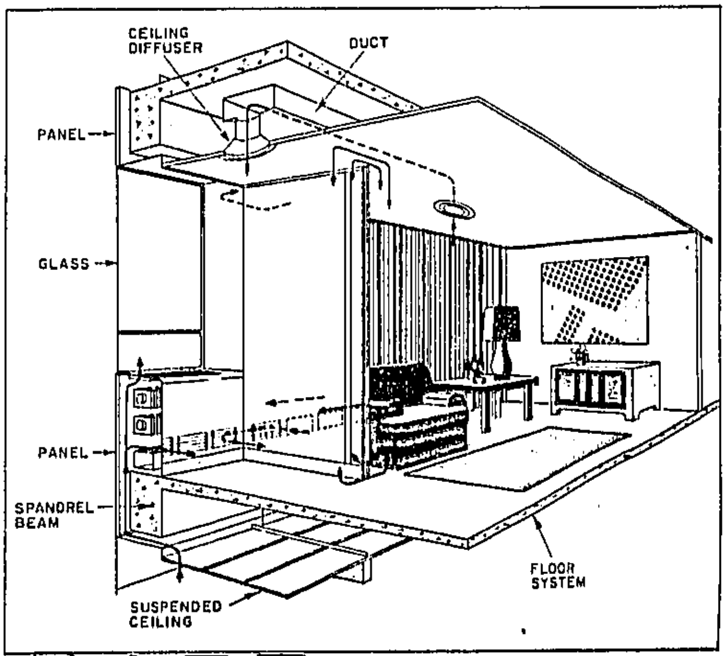


Figure 1—Numerous Paths for Sound Transmission Between Dwellings

mon to both the source and receiving rooms.

Transmission loss relates to the properties "of a single partition" and has no place in a building code unless specifications are given for all the important sound paths; even so, the transmission loss concept runs into trouble where the wall of one room is only partly common to the other room.

Quantity;

Airborne Sound Insulation, R' (ISO R717)[10] between rooms:

Definition:

$R' = \bar{L}_1 - \bar{L}_2 + 10 \log (S/A_2)$

Comments:

Source and receiving rooms adjacent, possibly with flanking transmission. This is the transmission loss of the common partition "as if" all the sound passed through the partition.

R' is the bastard rating: it purports to deal with the insulation between rooms but involves a correction for the surface area of the partition, S. Moreover, this rating has a strange status in ISO: R' is not mentioned in R-140[4], the measurement standards of ISO; it is introduced as a new measurement in the rating document, R717.[10]

The Airborne Sound Insulation, R', can be used only if the two test rooms have the entire partition in common. R' has the disadvantage that it intrinsically confuses the two concepts "between rooms" and "of a partition", but has the advantage of already being included in an ISO standard and is in use in a number of European countries.

Quantity:

Noise Reduction, NR (ASTM E336)[9] or Level Difference, D (ISO R140)[4] between rooms:

Definition:

$NR = \bar{L}_1 - \bar{L}_2$

Comments:

Source and receiving rooms not necessarily adjacent.

This is precisely the quantity we want to know in order to evaluate the privacy existing between two dwellings; the rooms in question need not be adjacent. It is very simple to measure.

The value of the Noise Reduction may be different, depending on the direction in which the measurement is made, that is, which is the source and which is the receiving room. In general, the value will be large when the room used as the receiving room contains the greater amount of absorption. There is no use arguing with this fact—the privacy itself will be greater in this direction. Therefore, from the building code point of view, the test should be done in the least favorable direction, namely, with the smaller (or least absorptive) room *used as a receiving room.*[5]

An alternative possibility is to normalize to a standard receiving room absorption as follows:

Quantity:

Area-Normalized Level Difference, D_n(ISO R140)[4]

Definition:

$D_n = \bar{L}_1 - \bar{L}_2 + 10 \log (A_0/A_2)$

(normalized to standard amount of absorption, 100 sq. ft., for example)

The meaning of normalization here is this: no matter what the condition of the building furnishings at the time of measurement, we correct (or normalize) the test results to correspond with what would be measured if the receiving room contained a standard amount of absorption, A_0, instead of its actual absorption, A_2, at the time of the test. In specifying a normalized level difference, a building code would call for a condition that is thought to typify most of the dwellings.

But A_2 may actually vary from 50 to 250 sq. ft. in the occupied and furnished rooms. Even if the building code requirement were met in terms of an area-normalized level difference, there could be +3 to −4 dB variation from the expectations of the code when the tenants move in.

Another alternative appears better in this respect: normalizing to standard reverberation time:

Quantity:

RT-Normalized Level Difference, D_n (ISO-R140)[4] between rooms:

Definition:

$D_n = L_1 - L_2 + 10 \log (T/0.5)$

A constant 1/2-sec. RT assumes that the (furnished) receiving room absorption is proportional to the volume of the room; this is reasonable for constant room height because the total room absorption tends to be proportional to the floor area in occupied apartments. The area of the common wall does not appear in this rating; thus, it is applicable whether the two rooms in question have a complete wall or floor in common, or only in part, or none at all.

If we normalize to 1/2-sec., which only acknowledges what is nearly the case in most occupied furnished rooms anyway, the test should be made with the smaller rooms as receiving room, because it contains the least absorption and will give the lower value for isolation.[5]

From the point of view of enforcement of noise control requirements in building codes, however, it is very inconvenient to have to measure the reverberation time of the receiving room, for this requires considerably more equipment than does the rest of the test procedure. There is a practical alternative, based on steady-state measurements of the receiving room absorption and on the fact, mentioned above, that the amount of absorption in a typically furnished living-or bedroom is approximately equal to the floor area of the room. The receiving room absorption A_t, at the time of the test, is measured by using either a calibrated sound source or a "near-field" steady-state measurement. This test result is used in the following equation to yield a very good approximation to the level-difference normalized to 1/2-sec. reverberation time in the receiving room; (see margin) where S_{fl} is the floor area of the receiving room in sq. ft.

$$D_n = L_1 - L_2 + 10 \log (S_{fl}/A_t)$$

van den Eijk has pointed out that it would be a considerable help to the architect designing the building if he had some guidance in predicting the isolation in the finished building. He proposes the following equation for level difference normalized to 1/2 sec; (see margin) where h is the dimension of the receiving room perpendicular to the common wall, TL is the transmission loss of that common wall (available from previous measurements on similar structures), and it is assumed that careful supervision during construction will render the sound transmitted by other paths negligible.

$$D_n = TL + 10 \log h/3 \quad (h \text{ in meters})$$
$$= TL + 10 \log h/10 \quad (h \text{ in feet})$$

Single number ratings

All the quantities discussed so far are supposed to be measured in bands of frequency, either octave-band or one-third octave-band. In some cases the assignment of a single-number rating has been standardized to simplify the rank ordering of partitions or room pairs as shown in the accompanying table.

Single Number Ratings

	Corresponding to:	*Rating*	*Reference*
Of a Partition	Transmission Loss, TL	Sound Transmission Class STC	ASTM E413[3]
	Field Transmission Loss, FTL	Field Sound Transmission Class, FSTC	ASTM E336[9]
Between Rooms	Airborne Sound Insulation, R'	Airborne Sound Insulation Index, I_a	ISO R 717[10]
	Noise Reduction, NR	Noise Isolation Class, NIC (not normalized)	ASTM E336[9]

The NIC is assigned to a set of NR data using the same procedure by which the STC is assigned to a set of transmission loss data. Rank ordering is particularly important in building codes because the "go/no go" concept, according to which the building will be approved for occupancy, demands ordering along a single scale, rather than trying to evaluate a set of octave-band or one-third octave-band data.

Unfortunately, none of these single number ratings is quite what we want for building code applications because they are not normalized. If the Noise Isolation Class (NIC) were normalized to 1/2-sec. RT, however, this would be a good choice: NNIC, the Normalized Noise Isolation Class. This quantity was introduced by Weston[12]; it is not yet defined in acoustical standards, but it should be. The NNIC based on one-third octave-band measurements would be a meaningful and reliable rating for building code purposes. Unhappily, it is not a simple measurement: it requires one-third octave band sound pressure levels to be measured in both source and receiving rooms, plus one-third octave band reverberation time data in the receiving room: 48 pieces of data altogether for each room pair.

Let us then seek a simpler scheme, where the measured data themselves are single numbers. The first possibility, which does not assign a rating at all, assesses true privacy (not just the isolation); it consists of measuring the existing background noise (A-weighted) in the receiving room, then turning on a standard broadband noise source in the adjacent room to see whether the receiving room level increases perceptibly. If it does not, then there is adequate privacy by definition, irrespective of any properties of the structure. Of course the spectrum and operating level of the source next door must be appropriately chosen to simulate household sound spectra realistically.

A practical objection has been raised to this procedure for a building code compliance test: on the day of the test, a knowing building owner might raise the background noise higher than normal (perhaps by stationing a compressor outside the building), so that faulty isolation would not be detected in the tests.

Other new possibilities would be the Isolation Index, and the Privacy Factor:

Rating:

Isolation Index, I, between rooms (proposed by the author February, 1971):

Definition:

$I = (L_{so} - L_{sr}) - (L_{ro} - L_{rr})$

where L_{so} is the A-level near the source in the source room

L_{sr} is the space-average A-level in the receiving room with source in source room

L_{ro} is the A-level near source with source now in the receiving room

L_{rr} is the space-average A-level in the receiving room, with source in receiving room

Comments:

If $L_{so} = L_{ro}$, then $I = L_{rr} - L_{sr}$; by contrast the Noise Reduction would be $NR = L_{ss} - L_{sr}$.

The Isolation Index is built on the assumption that privacy is usefully rated in terms of the sound level resulting in the receiving room from a given amount of *sound power* introduced into the source room; radiated sound power from a source is more likely to be constant than room sound level, as assumed in all other isolation measurement procedures. But perhaps it is too late to introduce this concept into our considerations at this time.

Rating:

Privacy Rating, PR, between rooms in the field (proposed by R. Huntley, February, 1971)[13]

Definition:

$PR = \bar{L}_1 - \bar{L}_2 - 10 \log A_2$

Comments:

$\bar{L}_1$ and $\bar{L}_2$ — are A-weighted sound levels and $10 \log A_2$ is determined by steady-state measurements of A-levels.

Privacy Rating, like the Isolation Index can be determined simply, without decay-rate measurements, and is independent of the room absorption. The Privacy Rating does not measure either the insulation of a wall or the isolation between rooms; instead, the privacy between rooms is defined in terms of the effective size of a hole in the party wall that would account for *all* the sound transferred from one side to the other, regardless of path. The receiving room absorption must be accounted for in the formula by a term similar to the $L_{ro} - L_{rr}$ term in the Isolation Index.

The Privacy Rating would not yield noise reduction or transmission loss, but would give numbers smaller by 10 log (party wall area); that is, about 20 dB less than customary wall rating values. Huntley's concept can be adapted to make a single-number "A-level version" of any of the preceding quantities except RT-normalized level differences, an example, see margin.

$R' = PR + 10 \log S \sim PR + 20;$

$D_n = PR + 10 \log A_0 \sim PR + 10$, if $A_0 = 10$ sq.m and A^2 is in sq.m (metric sabins)

or D_n PR + 20, if $A^0 = 100$ sq. ft. and A^2 is in sq. ft. (sabins)

Special requirements on sound source

For evaluating room-to-room privacy in terms of weighted sound levels alone, the spectrum shape of the excitation signal in the source room should be approximately constant for all tests. This requires the development of a standard noise source to be used in field tests. It must be powerful enough that the receiving room sound level can be measured in the presence of typical field levels of background noise. (The "non-rating" evaluation of privacy mentioned earlier, would not require such a powerful source.) The spectrum shape may be selected to give good correlation between the single-number rating and the complete Normalized Noise Isolation Class.

Recently, tests have been carried out[14] in the United States to see how well such a simple privacy rating can be made to correlate with the more complicated Normalized Noise Isolation Class rating. The first results, based on test examples of "pink noise" in the source room, are shown in Fig. 2. The difference between the A-weighted sound level in the source room and the A-weighted sound level in the receiving room appears to be about the same as the Normalized Noise Isolation Class on the average, with a standard deviation of about 0.8 dB.

The impetus for trying to establish such a correlation is that the Noise Isolation Class (closely related to the Sound Transmission Class) is already accepted by architects and building code officials as a proper measure of transmission loss. However, it has been shown recently[8] that the A-level difference between source and receiving rooms has as strong a claim to validity as the Noise Isolation Class in predicting the occupant's reaction with respect to their privacy, and the prediction is not very dependent on the source spectrum shape. Hence, the demonstration of correlation between the A-level rating and Noise Isolation Class or Sound Transmission Class turns out to be interesting but it is unnecessary to support the choice of A-level difference for use in building codes.

Because a standard tapping machine will be needed for tests of the impact isolation of the floor structures anyway, this same apparatus might be used to generate a signal for the airborne sound isolation test. Fig. 3 shows octave-band spectra noise in the source room generated when the standard ISO tapping machine operates on a sheet of plywood, suitably suspended 20" above the floor. The 3/8-in. plywood

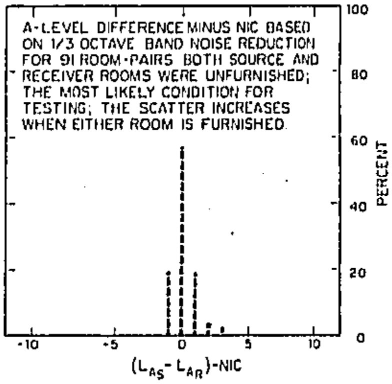


Figure 2—Results of Evaluations of a Simple Isolation Test Procedure

yields considerably higher levels than the 3/4-in. plywood. The levels in the high frequency bands are raised if the plywood is clad with a sheet of steel on the tapping surface. Even the shape of the spectrum would be acceptable.[6]

Alternatively, a loudspeaker may be driven with "pink" noise to somewhat higher levels, which would be an advantage in case of measurements in high background levels.

Existing codes and adequate privacy

Even as we try to develop noise control requirements in building codes that will really work,[12] it is important to ask how effective the existing codes are when they are vigorously enforced. Perhaps one may accomplish as much good with relatively simple isolation measurement techniques as with more complicated ones.

Consider the record in Denmark, where for over ten years a consistent program of noise control has been applied to dwellings and other types of buildings. The Danish building code[1] actually specifies only that the building authorities may require measurement of sound insulation to be carried out before the building is approved. Such measurement is not mandatory.

The Danish code first lays down requirements for the isolation between rooms (in terms of the least values that must be achieved in each third-octave band between 100 and 3150 Hz and an average value over the 16 frequencies, for various categories of building types—apartment buildings, terrace and semi-detached houses, school classrooms, etc. Then it goes on to specify the transmission loss of the party wall in each case that can be expected to meet the isolation requirements. The code suggests specific constructions that would normally satisfy these conditions. No explicit consideration is given to sound paths other than the one through the party wall or floor.

In practice, the requirements of the building code come into play when the architect's drawings are examined at the time the permit to build is issued. The permit for occupancy of the finished building is often given without a test measurement of the isolation achieved.

However, the Danish Ministry of Housing has been running a more-or-less continous program of noise measurements in buildings for years; the results are used to evaluate periodically the effectiveness of the building code and its enforcement.[7] Some of the results are shown in Fig. 4, which displays the cumulative statistical distribution of isolation field test results in apartment houses. From 1967–70, 60% of the tested apartments met the requirement of $\overline{NR} = 49$ dB. Some of the better results reflect the architect's choice of "luxury" construction: he was seeking to do better than merely pass the requirement of the building code.

Figure 5 compares these results with measurements made ten years earlier. Again, about 60% of the tests complied with the requirement of $\overline{NR} = 49$ dB; but note that in the earlier period there was a fad for very lightweight concrete construction that produced some disasters: 4% of the apartments had $\overline{NR}$ less than 34 dB. For noise isolation in row houses, the requirement ($\overline{NR} = 52$ dB) is 3 dB more stringent; about 50% of the tests met the requirement (see Fig. 6). The isolation statistics for school classrooms (see Fig. 7) indicate that 1953–56 was the best period for classroom construction from the viewpoint of adequate noise isolation.

Figure 8 gives the statistics for tests of impact isolation in apartment houses, where 70% of the resiliently-mounted wood floors passed the test, but only 15% of the hard floors passed. Similarly, in row houses (see Fig. 9) resiliently-mounted wood floors passed the test in 92% of the cases, but hard floors passed in only 32% of those cases where the source and receiving rooms were adjacent. In measurements of hard floors where the source and receiving rooms were not adjacent, 75% of the floors passed the requirement.

Even in a country like Denmark, which vigorously enforces its building code at the time of inspection of the building drawings and even maintains a continuing program of isolation measurements in the finished buildings, one cannot hope for 100% success. A typical achievement is

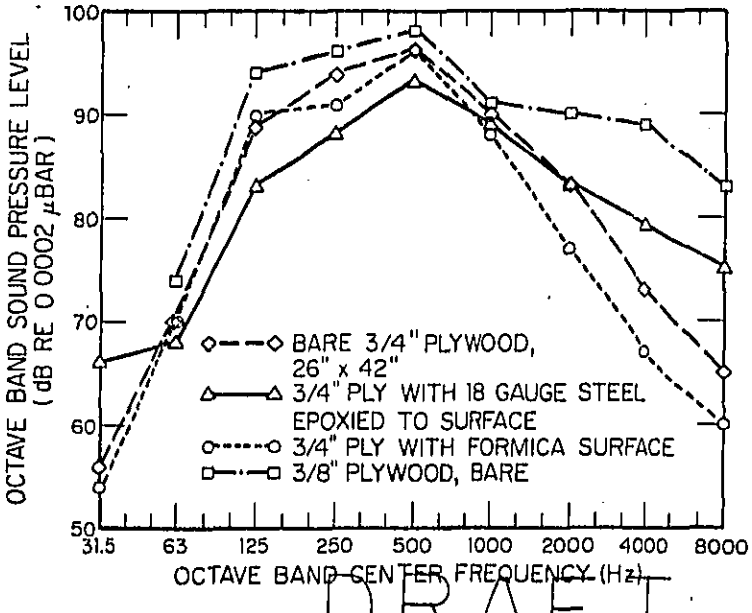


Figure 3—Spectrum of Sound Generated by Standard Tapping Machine Operating on a Resiliently Suspended Sheet of Plywood, 26" Above Floor

closer to 50% compliance with the requirement. Similar results have been obtained in Sweden and West Germany.

In East Germany, where the government writes the building code noise control requirements, constructs and owns the buildings, and performs the tests to demonstrate whether they pass the code requirements, no more than about 70% of the units comply with the code.

In all the dwellings discussed here (except for the misguided fad for light concrete in 1957–60) the basic construction had potentially adequate sound insulation; otherwise, the permit to build would not have been given. The trouble came during construction where poorly executed details of assembly allowed serious flanking transmission and sound leaks. There is simply no way to exercise control over this aspect of noise isolation except by requiring that the finished building pass specified isolation tests before the permit for occupancy can be signed. This requirement, if it is clearly understood by everyone beforehand, may supply the motivation for critical supervision and care in the construction so as to avoid spoiling an intrinsically good noise isolation design for the building by careless construction.

The price of failure

If even vigorous efforts to enforce noise requirements in building codes lead to compliance in only about half the dwellings, is this really serious?

To answer, one must ask how much may a building fail without a serious compromise of privacy for the tenants. Figure 10 shows a worksheet used in a well-known procedure for evaluating privacy against intruding speech sounds. This Speech Privacy Analysis[2] first determines a Speech Privacy Rating (SPR) for the dwelling in question in terms of the five elements that combine to give speech privacy: 1) vocal effort of the speakers in the source room; 2) sound absorption in the source room; 3) isolation existing between the two dwellings; 4) existing background noise level in the receiving room; and 5) the amount of privacy desired (for example, more privacy would be desired for a doctor's or a lawyer's office than for a secretarial office).

People in the United States are rather uncomfortable without any sound whatever coming from their neighbors; that leads to a sense of complete social isolation and lack of community. For normal privacy, people are satisfied if they can understand less than 5% of their neighbors' speech; for "confidential" privacy, just less than 1% understandability is satisfactory. The Speech Privacy Analysis is a simplified method for calculating the percentage of speech intelligibility existing between the dwellings in question, and the Speech Privacy Rating is the result of that calculation; the SPR increases as the intelligibility decreases.

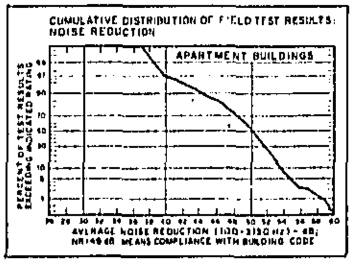


Figure 4—Danish Field Test Results: Noise Reduction in Apartments

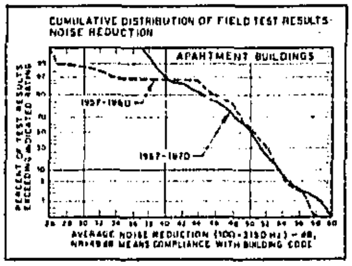


Figure 5—Danish Field Test Results: Noise Reduction in Apartments at Different Periods

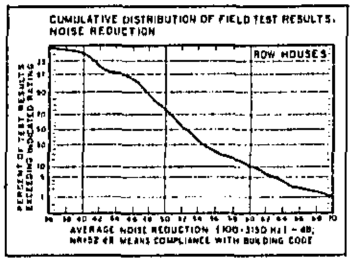


Figure 6—Danish Field Test Results: Noise Reduction in Row Houses

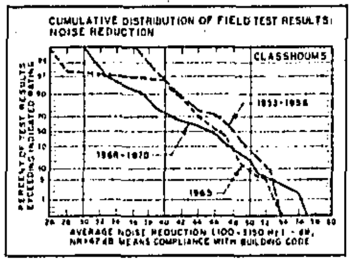


Figure 7—Danish Field Test Results: Noise Reduction in Classrooms at Various Periods

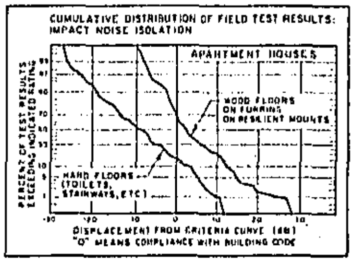


Figure 8—Danish Field Test Results: Impact Isolation in Apartments

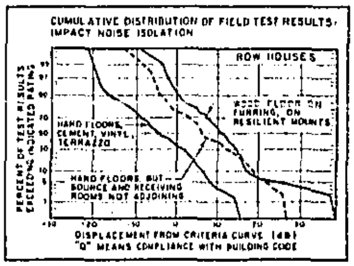


Figure 9—Danish Field Test Results: Impact Isolation in Row Houses

The isolation between the two dwellings and the background noise in the receiving room are completely complementary with respect to their effect on the Speech Privacy Rating: a decrease of 5 dB in isolation can be exactly compensated, as far as privacy is concerned, by an increase in background noise. Speech intelligibility hinges on signal-to-noise-ratio, not on the signal level alone. Thus,

[NOTE: The text of this page, as published, had some of the paragraphs transposed so that the "proposed approach" made no sense. This text is now in the correct order. T. J. S.]

there is a danger in specifying only the achieved isolation in a building code. Even if the specified isolation is achieved in the finished building, it will lead to the desired privacy for the tenants only if the background noise has the proper value. Because of this limitation, one should also specify complementary background noise in a building code to guarantee privacy.

What then, constitutes a serious failure? The curve on the worksheet of Fig. 10 shows that the entire gamut of tenants' reactions occurs in a range of about 15 dB. If the SPR is less than about 80, a change of 5 dB one way or the other will have no effect; the tenants will probably resort to legal action anyway. Or, if the SPR exceeds about 110, again a 5 dB change one way or the other will have no effect; the tenants will be unaware of any problem. The critical transition range affecting tenant reaction requires a change of only 5 dB.

If, as seems reasonable, the building code requirement is aimed at a condition where there is just barely some awareness of the people next door (say, SPR = 100), then a dwelling where the isolation fails to meet the requirement by 5 dB (achieving SPR = 95) will cause tenant complaints. A failure of 10–15 dB would lead to vigorous complaints and threats of legal action.

Let us return now to Figs. 4–9 to see how many of the tested Danish dwellings show "serious failure" in the terms just discussed. According to Fig. 4, 10% of the apartments tested in 1967–70 were seriously deficient (that is, exhibit achieved isolation 5 dB or more below the code requirement). From Fig. 5, in the period 1957–60, only 5% of the apartments were more than 5 dB below the requirement, but those 5% were very far below. From Fig. 6, for row houses (with a 3 dB higher requirement), 8% of the tests failed by 5 dB or more. For school classrooms, shown in Fig. 7, 12 to 35% failed by more than 5 dB, depending on the period; the most recent constructions were the worst!

A proposed approach to noise control in codes

We are currently working with a large American city to establish noise control requirements in their building code. We believe that this new code will retain the virtues of existing codes, but will introduce a significant improvement. The ultimate acceptance for occupancy of all housing will depend upon a specified amount of isolation between dwellings and a specified range of background noise being achieved in the finished building. At the time of application for a building permit, the architect's drawings for the building will be examined to see that he has chosen suitable basic constructions for the walls and floor/ceiling elements. If he has selected constructions known to provide noise isolation consistent with the desired values, the building permit will be issued.

So far, the procedure is the same as is followed in many European countries. The difference is that here the approval to build confers only tentative approval of the noise isolation of the building; accepting or correcting the architect's choice of basic constructions at this stage will amount only to guidance based on past experience. Detailed guidance will also be offered at this time on ways to avoid mistakes during construction.

The crucial test will come when the building is completed; a field test of the building must demonstrate that the specified privacy in fact has been achieved. It is proposed that privacy, in the new code, be determined by the sum of two numbers: the A-level difference, ΔL_A, between the source and receiving rooms and the A-weighted level, N_A, representing the background noise in the receiving room. This sum is called the Privacy Index, I_P. (This index has the advantage that no normalization is needed to account for differences in receiving room absorption: the effects on ΔL_A and N_A are equal and opposite.) The measurements in the completed building must demonstrate a value for I_P of at least 75 as a minimum requirement. One or two better grades of privacy ($I_P = 80$ and 85) will be defined, but not required, in case building owners want to be able to take credit for having provided better than the minimum privacy requirement.

The proposed procedure for evaluating the acoustic isolation in the completed building may require as many as three steps:

1) First, a simple screening test is made by a staff member of the city's building code department measuring isolation in terms of the difference in A-weighted sound levels, as described above and the A-weighted background noise level. (Normalization ΔL_A to standard receiving-room absorption, if desired, could be done by steady-state measurements or be reference to a table of corrections for different furnishings in the receiving room.) It is expected that this screening test will quickly show up the buildings that are clearly acceptable as well as those that clearly fail the requirements. Many buildings will be approved for occupancy based on the simple screening test alone.

2) If a deficiency in noise reduction or background noise level appears in the first test, it is repeated with more care under the supervision of an acoustical engineer. Based on this result, the building inspector will decide an approach for building occupancy.

3) If the inspector disapproves the building, the owner must arrange for

Figure 10—Worksheet for Speech Privacy Analysis

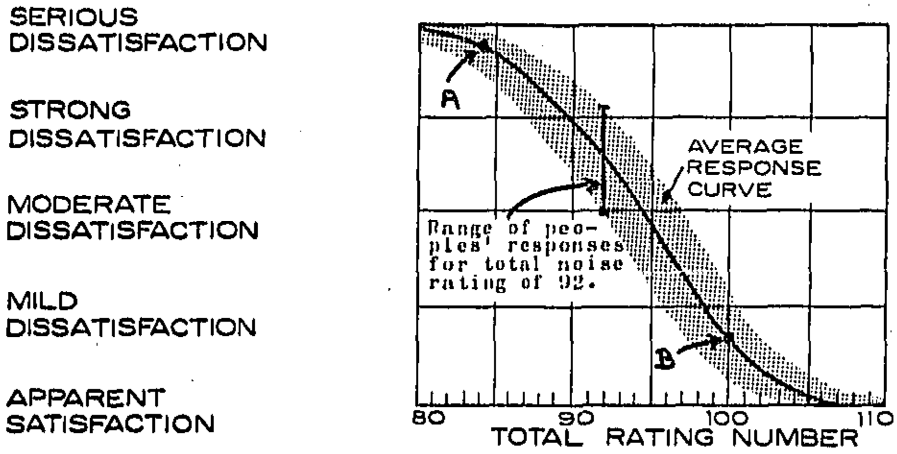
The Speech Privacy Rating accounts for all five important acoustic elements that determine privacy; each of these five elements is rated with a single number (in steps 1 through 5 on the worksheet) and the sum of these numbers comprises the Speech Privacy Rating (SPR). To predict the occupants' response, enter the figure at the top of the page with the SPR on the horizontal axis, move up to the curve and then left to the vertical axis.

DRAFT

SPEECH PRIVACY ANALYSIS

JOB NO.
SHEET NO.
DATE

ANTICIPATED RESPONSE TO PRIVACY SITUATION



RATING FACTORS:

	A	B	C
1. SPEECH EFFORT — LOUD 0, RAISED 5, CONVERSATIONAL 10 15 (APPROXIMATES LEVEL OF SOURCE ROOM SPEECH)	6	6	
2. SOURCE ROOM FLOOR AREA — 50 100 200 400 800 1600 SQ.FT. / 0 5 10 15 (APPROXIMATES EFFECT OF SOURCE ROOM SOUND ABSORPTION)	7	7	
3. ROOM-TO-ROOM NOISE REDUCTION RATING	56	72	
4. ADJACENT RM. BACKGROUND NOISE RATING	15	15	
5. SPEECH PRIVACY — CONFIDENTIAL 0, NORMAL 5 10 (DEGREE OF PRIVACY REQUIRED)	0	0	
TOTAL RATING NUMBER	84	100	

EXAMPLES:

A. EXISTING CONDITIONS BETWEEN LIVING ROOMS

B. SAME, WITH MODIFIED WALL CONSTRUCTION

C. ________

the more complicated procedures of the field transmission loss test (ASTM E336) in order to determine which part of the structure (i.e., which sound path) is at fault and should be corrected. Of course, the fault might be located without the need for detailed tests.

Only the first two steps are simple enough to be carried out by building inspectors; the transmission loss test would be conducted by professional acoustical technicians.

Formally, it will make sense for the code to specify the Sound Transmission Class (STC) of the various building components, to provide guidance in the initial design of the building and to make it simpler when the drawings are to be approved for a building permit. If the A-level difference in the finished building complies with values of isolation (privacy), additionally specified in the code, then there would be a waiver of the complicated transmission loss (ASTM E336) tests to demonstrate compliance of the individual building components.

There may be general opposition to this new building code approach at first; not simply because it introduces changes in an established procedure, but because the architect, the owner and builder have no guarantee, at the time the permit to build is granted, that the finished building will be approved, for occupancy. Understandably, they will regard this as a considerable risk, requiring a strong gambling instinct to go ahead with the project. On the other hand, when they *do* go ahead, they will undoubtedly provide good supervision to prevent "acoustical accidents" during the construction.

It is important to establish the principle of compliance with a performance specification while making the transition as palatable as possible to all concerned. Accordingly, we propose a step-wise approach toward achieving the ultimate privacy goal.

First, we decide the measure of isolation we will ultimately want to achieve in housing everywhere, and express this in terms of certain value of ΔL_A, say X. For about the first year after the code is in effect, only those constructions would be approved for building that can be expected to yield somewhat better performance than the ultimate goal, say X + 5. When tests are made in the finished building (again, during the first year or so), the building would be approved for occupancy even if it failed to meet the desired goal, by say 5 dB.

Under these conditions, there would be a 10 dB margin for error during construction . . . approximately what is being achieved at present. No sudden difficulties are imposed on the architect or builder immediately after the code goes into effect; the 10 dB margin should be comfortable for everyone concerned, and should allow the principle of performance testing to be painlessly established as the proper way to solve the problem.

Gradually, say, in two or three-year intervals as construction workers learn how to improve their assembly techniques to avoid leaks and flanking, the permitted 10 dB margin will be narrowed in steps. In part, more "speculative" constructions would be approved in the drawings at the building permit stage. Partly, also, the isolation requirements would be applied more strictly at the test of the finished building. After five to seven years a significant improvement in achieving privacy should be realized in all kinds of dwellings. The main object of this step-wise approach is to make the enforcement of, and compliance with, the new code immediately practicable, and at the same time attractive to all concerned as the "right" way to set about improving the privacy in our dwellings. **N**

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About the author . . .

THEODORE J. SCHULTZ could easily have wound up playing in the concert hall instead of becoming a scientist jousting with phenomenological enemies of the concert hall. When he first entered the University of Rochester's Eastman School of Music, he harbored intense ambitions to become a professional musician. After a year or so of observing members of the famous orchestras and other ensembles returning wearily after a concert in their dirty white ties, Ted Schultz decided that the lifestyle wasn't for him, even if music was. Even today you'll find Ted playing music—on a harpsicord and on ancient instruments that he has restored for the Museum of Fine Arts and in a chamber orchestra that gives concerts there.

But the steps toward becoming Principal Scientist—Acoustics, and Technical Director of Architectural Acoustics and Noise Control at Bolt, Beranek and Newman, Cambridge, Mass. really began with Schultz's attempt to retain an association with music while pursuing an engineering career that seemed a more appealing way of life. That route, via the Universities of Missouri, Texas, the U.S. Naval Academy and Harvard, resulted in a Ph.D in acoustics. It also piled up professional experience as an instructor in physics, mathematics and electrical engineering at the Naval Academy, Research Physicist at Naval Research Laboratory, Research Fellow in Acoustics at Harvard, Assistant Chief of the Acoustics Section at Douglas Aircraft.

He has been with BBN since 1960 where his more recent work has dealt with problems of measurement and design in architectural acoustics, design and evaluation of acoustical testing laboratory facilities, noise and vibration criteria and control for high-speed trains and for aircraft.

Meanwhile, Dr. Schultz has been active in writing and reviewing acoustical standards at national (ASTM and ANSI) and international (ISO) levels. He has prepared, for the U.S. Department of Housing and Urban Development, a set of guidelines substantiating their recently adopted policy of withholding support for housing proposed for locations judged to be too noisy for suitable living environments. Not long ago he spent six months in Europe visiting numerous laboratories to assess the state of ongoing acoustical research and to investigate enforcement of noise ordinances and noise control requirements in building codes.

All of this has left Ted Schultz discontented with the scientific establishment. He notes a tendency for scientists to tackle what they think they can measure and that forecloses a lot of problems of the real world. Right now, says Schultz, we seem to be on the threshold of finding out what annoyance really is, a critical key to noise control problems. He is more concerned with the quality of life than physical phenomena that turn out to be handy to quantify.

Schultz's own mode of living reflects those concerns. His handsome townhouse, once a burned-out brownstone he restored, is not far from the jutting modern architecture of Boston's Prudential Center. The fourth floor is a verdant retreat from the bustling city—call it an achievement in plant parenthood. Ted maintains a huge greenhouse which is the home of cast-out plants from nearby Harvard. His biologist friends at the university receive plants for identification from all over the world and, for lack of room, pass them on. A local TV crew recently tried to contrast this top-floor terrarium with the noisy city outside. Alas! Their microphones could hardly pick up a sound.

APPENDIX G

"Owner's Viewpoint in Residential Acoustical Control"

Frederick P. Rose

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THE JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA VOLUME 36, NUMBER 4 APRIL 1964

S4

Owner's Viewpoint in Residential Acoustical Control

FREDERICK P. ROSE

Rose Associates, Inc., 529 Fifth Avenue, New York, New York

Stress is laid on the lack of adequate acoustical treatment in the design and construction of multiple dwellings in the United States of America.

THE most startling fact I can present to this Symposium is that, in this year of grace, at a time of broad architectural achievement in every sphere of building activity, when structural systems not even imagined a generation ago have become commonplace, and mechanical design is available of such sophistication, we can create any climate, lighting mood, or transportation at the touch of a switch. When all this is going on all over America in every type of building—at this momentous period of building history— there is absolutely nothing being done about acoustical treatment.

Of all the complaints owners throughout the country hear about postwar apartments, lack of soundproofing heads the list most frequently. There isn't even a close second.

It is unfortunate that much of the general public equates a noisy apartment with "shoddy construction." Nothing could be further from the truth. For, although I will be the first to admit that adequate soundproofing of our new buildings is lacking, I also feel most strongly that todays' construction techniques are far superior to those of the past. But the irate tenant, disturbed by his neighbor's children, television, or plumbing, is not interested in such details. He wants a good night's rest, and the privacy of his home free from intrusion or concern that the noise that he generates will be offensive to his neighbors.

The source of the problem is often found in architectural design, as soaring costs have resulted in smaller apartments with increased density.

Older buildings simply had more structural mass, which is the most effective means of reducing the transmission of sound. Stone concrete was more frequently used with deadening on top of floor slabs, and $\frac{1}{2}$ to $\frac{3}{4}$ in. of plaster below, and ceilings were higher. Partitions were not only heavier, but had full thickness of plaster on both sides. Doors were thicker and usually solid. Interior decorating styles ran more to overstuffed furniture, heavy draperies, and rugs, all of which served to absorb sound. All these factors helped reduce noise.

Today, lightweight concrete is more often specified, which has less mass and transmits sound more readily. Moreover, there is usually only a thin flooring of resilient tile or $\frac{13}{16}$ in. of wood parquet applied directly over the slab, instead of the subflooring or sleeper systems formerly used. We now favor thin, plaster skim coats on ceilings to save money and at the same time reduce floor thickness. These tendencies, which contribute to easy sound transmission, have been encouraged by our zoning regulations, which place limits on building heights. Owners insist that their architect get the greatest number of floors in a given height not only by cutting floor thickness, but by using the minimum ceiling heights.

The dining room has all but disappeared, and open planning has brought the kitchen into the living room.

The efficiency, or no-bedroom apartment, is ubiquitous, and even the most ingenious architect finds it impossible to avoid placing one tenant's kitchen next to another's bedroom, or a bathroom near a living room. To aggravate the problem even more, we have produced a vast array of noise-making equipment—dishwashers, garbage disposals, television, stereo, air conditioners, and many other loud gadgets and toys. The total effect is disastrous.

Impact noise occurs when the floor or wall is set vibrating by direct or mechanical contact with the producer of the sound. The sound is radiated from both sides, and is probably the greatest single source of annoyance to an apartment dweller. However, the physical solution to the problem is no mystery.

In office buildings, we have made all the advances required by current structural and mechanical conditions because we are a business-oriented country, and in our places of work we would not tolerate the second-rate standard that we accept in our homes. For example, air conditioning became common in office buildings long before the public demanded it in residences. We use various vibration-elimination devices when necessary, and, as an answer to special requirements for electric service, air conditioning, and load distribution of heavy and complicated computers and other business machines, we have developed "floating floors." High-velocity three-pipe air-conditioning systems are available, by means of which each tenant on any day of the year can demand and get the exact temperature and humidity that he wants.

The list could go on and on—special heat-resistant glass; special metallic alloys; new skins and new bones in the form of high-strength steels. In effect, new everything but residential acoustical treatment.

Last year, I had the honor of serving as a member of the United States Delegation to the United Nations Housing Conference in Geneva. After the official meetings, about fifty delegates from over thirty countries were invited by the governments of Great Britain and the Republic of Ireland to study the housing inventories of each country, and to offer comments, criticisms, and suggestions.

I was amazed to discover that the minimum standards of sound control for their lowest level of public housing (roughly equivalent to projects of the New York City Housing Authority), far surpassed the best that we do for our most expensive apartments and homes. For example, a typical European reinforced-concrete high-rise building will control horizontal sound transmission with concrete sheer walls or 8 in. of solid masonry plastered both sides. Vertical noise will be controlled by the construction of a 6- or 7-in. concrete arch covered with a 2-in. layer of Fiberglass or other insulation board, 2 in. of loose sand, and a 2-in. cement screed coat covered by resilient tile. Often, electrical wires are imbedded in the screed coat for the purpose of radiant heating. When wood floors are used, sleepers are placed on the loose fill and then underflooring nailed thereto. On the underside of the concrete slab, there would usually be three coats of plaster. Plumbing stacks are completely isolated, and noise of the steam system is no problem, as our type of central heating is generally not used. They will put up with medieval plumbing and open fires for heat, but privacy is essential.

Compare this to our $100-per-room-per-month Park Avenue jobs, which accoustically differ little from our public-housing renting for a tenth of this figure: horizontal division is by means of $2\frac{7}{8}$-in. open-truss steel studs to which are attached (in the better buildings only) $\frac{1}{4}$-in. pencil rods holding resilient clips with $\frac{1}{2}$ or $\frac{5}{16}$ in. of solid gypsum board, covered on each side with two coats of plaster. These partitions are usually pierced by-to-back television outlets and other electrical outlets with no insulating barrier, and are as effective as an umbrella with a hole. Where plumbing stacks occur in a party wall (inexcusable design!), a wire-lath partition with three coats of plaster often suffices. More often than not, the wire lathers, who have no more training or interest in acoustical control than the builders or construction superintendents, will tie the channels supporting the lath directly to the plumbing or heating stacks, thereby *insuring* transmission of noise. Wood frame and semifireproof 6-story buildings are as bad or worse.

Ten years ago, in a New York "luxury apartment building," we conducted a series of experiments, using all of the then-current acoustical-control devices, and with a sound meter measured the *actual* decibel loss. To no one's surprise, we found that the laboratory results, proudly reported in the building-material companies' literature, were completely at variance with the results achieved in the field. Consequently, our office instituted a procedure of having acoustical consultants review all plans, and follow up with regular site inspections as the work goes on. This represents considerable improvement over general practice, but still is not comparable to the minimum standards set by foreign countries.

Another method that we use is to train our management personnel to try to settle acoustical disputes between tenants by convincing the noise producer to allow us to oil his noisy dishwasher, cushion an offensive Hi-Fi set, etc. We can do nothing about his wife's spike heels on a kitchen floor, or the crying baby in a bedroom next to someone else's living room. As a palliative, we require 90% of the floor area to be carpeted.

It was also emphasized by the other builders, architects, and housing officials at the United Nations Conference that a requirement for acoustical control is an integral part of the building codes of every other country in the world, and, while it would be unthinkable for our sanitary or structural codes to be less than perfect, the delegates from France, Bulgaria, Portugal, etc.,

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were astonished to find that in America such sound-deadening requirements did not exist.

I would hesitate to recommend that our already overworked Building Departments be given this additional responsibility, and I doubt seriously whether a 5% to 8% increase in cost, which would be the result of a really effective job, would be willingly borne by tenants in today's highly competitive rental market.

Would Mrs. Smith who pays $150 a month for a noisy apartment be willing to pay $160 for a quiet one, any more than Mrs. Astorbilt living in a $500 suite be willing to pay $540 for peace and privacy?.

I do not claim to know the answers, but one would have to be deaf as well as stupid to be unaware that the problem exists.

All housing, produced at all rental levels, is subject to supervision in design and construction by parties with a major fiduciary interest: the Federal Housing Administration, the State or City agencies having jurisdiction, or, in conventionally financed buildings, the insurance company or bank supplying the mortgage. Possibly some requirement should be demanded at this level.

In any event, the USA cannot continue to bring up the rear in this vital field, and, with the help of acoustical engineers, good builders, and aroused public officials, I know the problem can be solved. Medical societies warn of dangers to the public's health, and the American Institute of Architects decries ugliness. Why does not the Acoustical Society of America spearhead the drive for quiet buildings?

Where do we go from here? One possibility is the setting up of the minimum standard, in a manner similar to the insurance ratings of the National Board of Fire Underwriters. Acoustical engineers, architects, and builders, approaching the task with the proven American method of cooperation between industry, the professions and government, can do the job.

Let's get started!

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7. "Tentative Method of Laboratory Measurement of Impact Sound Transmission through Floor Ceiling Assemblies Using the Tapping Machine," ASTM Designation E493-73T, 13 July 1973, American Society for Testing and Material, Philadelphia. Two alternative ASTM test methods for measuring impact noise transmission, using a modified tapping machine, in one case, and a live walker, in the other, are currently in preparation; they should be available in late 1976.

8. "Field and Laboratory Measurements of Airborne and Impact Sound Transmission," ISO Recommendation R 140, 1st edition, January 1960; International Standards Organization, Geneva. This standard is currently being revised; the new version should appear in 1976. The revision is substantial, the new document comprising eight separate parts, dealing with:

   I. Requirements for laboratories
   II. Statement of precision requirements
   III. Laboratory airborne sound insulation measurements of building elements
   IV. Field measurements of airborne sound insulation between rooms
   V. Field measurements of airborne sound insulation of facades and facade elements
   VI. Laboratory measurement of impact sound insulation of floors
   VII. Field measurements of impact sound insulation of floors
   VIII. Laboratory measurement of the reduction of transmitted impact noise by floor coverings on a standard floor.

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