COMMISSION OF THE EUROPEAN COMMUNITIES

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CLASSES OF ACOUSTICAL COMFORT IN HOUSING

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CLASSES OF ACOUSTICAL COMFORT IN HOUSING

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The authors naturally assume full responsibility for the content of the present report.

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I - INTRODUCTION

One of the roles of the European Community Commission is to contribute to the lowering of technological barriers between nations through the establishment of a common technical language. Another objective is to contribute to the improvement of the quality of life of Europeans.

The first aim is to improve exchanges between European countries and to facilitate the task of the builders who want to expand their activities throughout the Community. Until to-day, the laws, rules and standards of each country have remained distinct, in general, and have been in fact obstacles to free circulation, since these documents have most of the time mirrored local technology. To generalize such rules to the whole Community has proven difficult and unnecessary.

The second goal, which is not less important than the first, consists in bettering the environment in which we live by requiring more severe standards of comfort.

Building acoustics, which is one of the areas of action selected by the European Community, is perfectly adaptable to performance recommendations : the present study is an attempt at establishing classes of acoustical comfort in housing. Acoustical comfort is defined as the ability of buildings to protect the users against noise and to provide an acoustical environment suitable to human activity.

The various steps of the present report are the following : after comparing the laws, standards and recommendations of the European Community member nations, a set of parameters and criteria to be used in a class system are defined. Five basic classes of acoustical comfort are then proposed.

The effects of the type of area in which the building is erected and of the kind of housing are analysed to demonstrate how the classes are to be used. An approximate economic evaluation of the five classes is then performed which shows the financial constraints tied to each of them. Finally the measurement and control methods to be used for the implementation of the class system are developed . In conclusion, suggestions are made on the potential uses of the class system and on the possible improvements of the national recommendations.

It should be stressed here that national and international standards relative to building noise control evolve constantly. While this report was being prepared, some Danish, Dutch, German and international documents were being revised and some new ideas on impact noise were being generated. The results of these endeavours should be used, in time, to modify and enrich the system developed here.

The system of acoustical comfort classes described here is a contribution to the investigation of the compatibilities of the various acoustical comfort evaluation methods. It is presented as a flexible frame which can easily be modified and adjusted as the national requirements and measurement methods evolve. It is the hope of the authors that their work will ultimately lead, after consultations with all interested parties, to a common, if not mandatory, scale of acoustical comfort in housing.

2 - CHOICE OF ACOUSTICAL PARAMETERS AND CRITERIA

2.1 - Background Information

In order to establish a classification of housing according to its acoustical performance, one must first define acoustical comfort and analyze the various parameters that may be selected to describe it.

Human beings are affected by structure-borne acoustical phenomena either in the form of airborne sound, of vibrations or of structure-borne sound. The first type of signal is perceived by the ear if its frequency is approximately between 20 and 20 000 Hz.

Some other types of acoustical phenomena may be of importance, ultrasounds which have frequencies above 20 000 Hz shocks, etc. However, too little is known about their effects on people to include them in our present classification. The existing legal documents and standards have in fact neglected infrasound, ultrasound, vibrations and shocks : the only texts which mention one of those phenomena have been published by the Federal Republic of Germany[1] and the International Standardization Organization[2].

The only physical process[3-5] that will be considered in the present report is the pressure variation in air due to sound waves. The quantity used to describe such waves is the sound pressure level which can be measured with a sound level meter, in dB. Sound level meters are provided with filters and weighting networks, such as octave and third-octave band filters and A-weighted networks. The former are used to measure the spectrum of the sound while the latter simulates the different sensitivity of the ear to various frequencies.

To investigate the effects of noise on human beings, its sound levels can be measured and correlated to the annoyance that it generates. It is then possible to choose the value of a noise level or of a noise descriptor which corresponds to a given acoustical comfort. It is affected by the nature, number and power of the noise sources inside and outside the building such as :

- Human sources : voice, steps, movements, radio, television.
- Individual equipment : apartment heaters, washing machines and other domestic equipment .
- Collective equipment : heaters, lifts, transformers, air conditioner.
- Outdoor noise : automobile, bus, railway, aircraft noise, industrial noise etc ...

Acoustical comfort also depends on the characteristics of the building. The transmission of sound waves through the walls, windows, ducts, shafts, openings and the transmission of vibrations through the structure will determine the sound pressure level resulting in a room from all the indoor and outdoor sources.

The following sections will analyse the technical parameters which are used throughout the European Community to evaluate the acoustical insulation of a house or apartment building and will review the measures of acoustical comfort and their relationship with these parameters.

The national laws and standards which will be under scrutiny in the following chapters are those of Belgium (B)(6), the Federal Republic of Germany (D)(7), Denmark (DK)(8), France (F)(9), Great Britain (GB)(10) and the Netherlands (N)(11). The rules used in Ireland are identical to those of Great Britain or the International Standardization Organisation. In Italy and Luxembourg, legislation is being prepared.

An international standard will also be quoted: ISO R 717 labelled "Rating of Sound Insulation for Dwellings"[12]. Bibliographical data is available in a recent EC[13] study on European Community standards relative to the protection of human activity in housing.

Referring to the standards used within the European Community[6-12], isolation* of a dwelling against noise fits into 4 categories :

1) Isolation against airborne noise generated indoors by people, radios, household appliances, etc ..

2) Isolation against impact noise (footsteps, falling objects, household appliances on the floor, chair movements, etc ..)

3) Isolation against noise from collective or individual equipment(lifts, central heating, water taps, etc ...)

4) Isolation against outdoor noise (traffic noise, industrial noise, school noise etc ...)

2.2 - Isolation against Airborne Noise due to Human Activity

When one examines the various standards in use in the countries of the European Community, in this case, three major differences appear :

1) The parameter used to rate the isolation between two apartments ,

2) The frequency bands within which the measurement parameter is determined ,

3) The criterion of acoustical comfort .

* The terminology suffers a great deal of confusion, even among specialists. **Insulation** has to do with the noise reduction properties of a given element (partition....) while **Isolation** is the overall noise reduction for all the airborne or solid-borne transmission paths.

2.2.1 - Measurement Parameter

In the determination of the isolation against airborne noise due to human activity, two methods are used commonly throughout Europe : the first requires laboratory measurements while the second calls for "in situ" measurements*.

The major difference between the two is the following : in the laboratory the emitting and receiving rooms are designed in such a way that sound can be transmitted from one volume to the other only through the separating partition (wall or floor) and that no flanking transmission occurs (lateral walls and floors).

The "laboratory" Sound Reduction Index R,(or insulation) in dB, can be determined from the measurements using :

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

where

- L_1 is the sound pressure level in the emitting room in dB
- L_2 is the sound pressure level in the receiving room in dB
- S is the area of the separating wall or ceiling in m^2
- A is the equivalent area of absorption of the receiving room in m^2

The term 10 log $\frac{S}{A}$ is designed to bring a correction to the measured values of the transmission loss index which does take into account the size of the separating partition as well as the characteristics of the emitting room which vary from one laboratory to another. Then only the specifications of the partition, material, thickness and mode of construction affect R and the values obtained in different measurement laboratories can be compared.

* The reader should be aware that the symbol R is used for results obtained in the laboratory and the symbol R' for "in situ" results.

If the measurement is performed "in situ", the acoustical energy is transmitted from one room to the other through the partition and through the flanking walls and floors according to the characteristics of each element. The sound reduction index measured "in situ" will not reflect only the transmission loss through the partition under scrutiny but any direct and indirect transmission.

The values obtained "in situ" and in the laboratory may in most cases be different. A different index is then needed to differentiate the two methods.

The standards used throughout the European Community differ in their choice of an index : for example, in the Federal Republic of Germany[7] the isolation between dwellings is determined "in situ" with :

$$R' = L_1 - L_2 + 10 \log \frac{S}{A} \qquad (2)$$

The Belgian[6], British[10], Danish[8], Dutch[11] and French standards[9] use instead measurements of the normalized level difference D_n, defined as :

$$D_{n,A} = L_1 - L_2 + 10 \log \frac{A_0}{A} \qquad (3)$$

or :

$$D_{n,T} = L_1 - L_2 + 10 \log \frac{T}{T_0} \qquad (4)^*$$

In the previous equations the variables are defined as follows :

- L_1 is the sound pressure level in the emitting room in dB
- L_2 is the sound pressure level in the receiving room in dB
- S is the area of the separating wall between these rooms in m^2
- A is the equivalent area of absorption for the receiving room in m^2
- A_0 is the equivalent absorption area of reference equal to 10 m^2 for apartments
- T is the reverberation time in seconds
- T_0 is the reference reverberation time in the receiving room equal to half a second for apartments

* $D_{n,T}$ is defined in the revised version of ISO-R 140 [24].

Note that in equation (2), the characteristics of the flanking paths have not been taken into account in the corrective term $10 \log \frac{S}{A}$, since S is the area of the partition alone : the flanking transmission enters only into the measured levels difference $L_1 - L_2$. In equations (3) and (4), the measured levels difference is corrected using the characteristics of the receiving room, A or T. The latter approach seems more logical.

Originally, the reason behind the use of R' instead of the index D_n has been an attempt to simplify the task of the users. In fact, by imposing rules based on the normalized level differences $D_{n,A}$ or $D_{n,T}$ one does not give directly information to the architect or the engineer on the acoustical quality of the separating or flanking walls or on the influence of the surface S. One must also remark that the use of the index R', according to ISO[12], is restricted as follows : "where the common area is less than about $10m^2$, or where no common partition wall surface exists, the quantity S should be replaced by the reference absorption of $10m^2$. In such cases R' is replaced by the normalized level difference D_n according to the ISO recommendation 140[24], clause 3.5".

The above remarks would tend to drive to the use of the normalized level difference D_n rather than the transmission loss index R'. A comparative study of R' and D_n indicates however that, in fact, for current building technology , the two parameters have similar values.

Specifically, it is possible to compare R'to $D_{n,T}$ and R' to $D_{n,A}$ by substracting equations (3) or (4) from equation (2). One obtains :

$$R' = D_{n,A} + 10 \log \frac{S}{A_o} \qquad (2) - (3) = (5)$$

and

$$R' = D_{n,T} + 10 \log \frac{S \times To}{A \times T} \qquad (2) - (4) = (6)$$

Using Sabine's formula :

$$T = 0,163 \frac{V}{A}$$

with

$$T_o = 0,5$$

$$R' = D_{n,T} + 10 \log \frac{S}{V} + 5 \qquad (7)$$

It appears clearly from equations (5) and (6) that the differences between the parameters R' and $D_{n,A}$ or $D_{n,T}$ depend on the dimensions of the separating wall. In Europe, the area S of the separating wall is close to $10m^2$ and the volume of the rooms is about $30m^3$.

Then,

$$R' \simeq D_{n,A} \simeq D_{n,T} \tag{8}$$

In standard buildings, the area of the walls varies usually from 8 to $13m^2$ and the corresponding volumes of the rooms from 25 to $50m^3$ (i.e. rooms with floors between 10 to $20m^2$). The differences between R' and $D_{n,A}$ or $D_{n,T}$ due to these variations are then :

$$R' - D_{n,A} = \pm 1 \text{ dB} \tag{9}$$

$$R' - D_{n,T} = {}^{+0}_{-1} \text{ dB} \tag{10}$$

As a result, the values of the R' parameter and the $D_{n,A}$ and $D_{n,T}$ parameters are equal within $\pm$ 1 dB for standard dwellings. However, the use of $D_{n,A}$ and $D_{n,T}$ should be preferred since their definition has been shown to be logical.

After this demonstration, we are now left with the choice between the normalized insulation referred to a reference equivalent absorption area of $10m^2$ or to a reference reverberation time of half a second, that is $D_{n,A}$ or $D_{n,T}$. It seems that $D_{n,T}$ should be preferred to $D_{n,A}$. In practice, it has been seen that the variation of the reverberation time is less than the variation of the equivalent absorption area. The reason is that in general the larger the room or the apartment, the larger the area of the walls, of carpeting and the other absorbing elements and the larger A. According to Sabine's formula, A and V are connected through the formula : formula :

$$T = 0,163 \frac{V}{A} \tag{11}$$

T being the reverberation time of the receiving room in seconds

V the volume of the room in m^3

A the equivalent absorption area as defined by :

$$A = \sum \alpha_i \; S_i \tag{12}$$

where α_i is the acoustical absorption of materials in % and S_i the respective area in m^2.

This means that when V and A increase, but not necessarily in the same proportion, then T varies only very little. Therefore, a reverberation time T of half a second would be representative of most circumstances where an equivalent absorption area of $A_o = 10m^2$ may not be adequate. In addition, one may remark that the reverberation time is a quantity that can be measured directly. The equivalent absorption area A can be obtained only through calculation. We conclude that the use of the normalized insulation $D_{n,T}$, because of its definition, seems to be the most adequate to define the insulation against airborne sounds between houses or apartments. The use of the acoustical transmission loss index R' is also possible provided the following precautions have been taken :

1 - The separating wall is identical whether it is seen from the emission or reception room.

2 - The surface S is close to $10m^2$ and the volume close to $30m^3$.

If these conditions are not fulfilled, the quantity $D_{n,T}$ alone should be used to describe the total isolation against airborne sounds between two rooms. The index $D_{n,T}$ has the advantage that it can be connected to the acoustical comfort independently of the specific characteristics of the building.

2.2.2 - Frequency Bands for the Determination of the Measurement Parameter

The ISO [12], German[7], Belgian[6], and British[10] standards or regulations require that the measurements of the indices R' or $D_{n,A}$ or $D_{n,T}$ be made"in situ" in 1/3 octave bands. The French[9] and Dutch (11) standards prefer to recommend measurements in octave bands. The first method leads to a fine analysis of the spectrum of the isolation parameter which turns out to be extremely useful in the case when the requirements of the standards are not met. It is then possible to find some of the reasons for the lack of isolation against airborne noise through the presence of resonance frequencies, coïncidence frequencies or leaks. But it has also the disadvantage of being longer to perform than the second, since it requires measurementsin 16 different frequency bands instead of 6 for the French system and 5 for the Dutch system which recently has called for an analysis over 5 octave bands centered on the frequencies 125, 250, 500, 1000 and 2000 Hz. However again, the measurements performed in octave bands have the disadvantage of giving only a rough spectrum analysis which, when the result is not satisfactory with regard to the requirements of the standards, may not always be sufficient for further investigations. This requires to repeat the measurement with narrower frequency bands.

Therefore, we conclude that none of the two systems is completely satisfactory and that it would be useful to use the two methods according to circumstances, that is to measure in octave bands when it is required only to check"in situ" the conformity of the construction to the standards and to use the third-octave band measurements when a finer analysis is required. In such a case, the third-octave frequency bands from 100 Hz to 3150 Hz would be used. In the long run, one may expect to be able to use single-number tests for airborne and solid-borne noise isolation when their correlation with subjective judgement has been proved adequate[37][49].

2.2.3 - Acoustical Comfort Parameter

Now that we have defined the quantities which can be used to measure the insulation against airborne noise in housing, we have to determine a qualitative scale which will be related to acoustical comfort. Two different approaches can be chosen.

The first one relates the acoustical comfort to the acoustical properties of the partitions surrounding an apartment (walls, floors and ceilings).

The second expresses the acoustical comfort not as a function of the insulation of the walls, but in terms of the effect that the insulation has on the transmission of a given noise level.

The first method is based on the standard DIN 4109[7] which has inspired the ISO standard R 717-1968 (E)[12] or to a least degree the Belgian standard NBN 576.40-1966[6] and Dutch standard NEN 1070 [11].

The German standard sets a reference curve which is a limit to the spectrum of the sound reduction index R' as determined by "in situ" measurement (see fig. 2.1). This curve represents, except for some details taking into account the characteristics of the ear, the acoustical transmission loss index curve that would be measured for a 25cm brick wall plastered on both sides[14]. This wall has been chosen because it has been found in practice to give a satisfactory insulation to airborne noises between apartments. When comparing the curve obtained from the "in situ" measurement of the acoustical sound reduction index with the reference curve, it is possible within each frequency band to determine the differences between the two curves and to compute the average deviation. Note that only the negative differences are considered, that is only the lack of insulation with respect to the reference curve. The average difference which has been thus computed cannot exceed 2 dB.

If it does, the reference curve is shifted by steps of 1 full dB until the average difference is larger than 1 and smaller than or equal to 2 dB. The number of dB by which the reference curve has to be moved corresponds to the insulation margin to airborne sounds ,that is ,to the index Ma as defined by ISO or to the index LSM as defined by the German standard DIN 4109.

The ISO standard requires, in addition to a limiting value of the average difference, a maximum difference not to be exceeded with respect to the reference curve. This maximum difference is 8 dB in third-octave bands and 5 dB in octave bands.

It must be noted that another acoustical comfort index is becoming popular in Germany that is the "weighted insulation index" R_W (Bewertetes Bauschalldämass[15]) which, in fact, corresponds to the airborne sound insulation index Ia as defined by the ISO standard R 717-1968 (E), that is :

$$Ia = Ma + 52 \text{ dB} \tag{13}$$

or :

$$R_W = LSM + 52 \text{ dB} \tag{14}$$

Ia and R_W are obtained by reading on the shifted reference curve the value of the acoustical transmission loss index R' in the frequency band (octave or third-octave band) centered on 500 Hz. This new approach turns out to be necessary because it is difficult for the layman to understand that an insulation that would be satisfactory can be expressed by a number equal to 0 dB or even that there can be negative values of the insulation. The required values for a minimum acoustical comfort between two dwellings is an insulation margin LSM = 0 dB (i.e. R_W= 52 dB) .

The Dutch standard NEN 1070[11] defines five required values for the normalized level difference $D_{n,T}$ in five octave bands centered on the frequencies 125, 250, 500, 1000 and 2000 Hz and which are within a few dB of the curve required by ISO or by DIN (see fig. 2.2.). They are normalized to a receiving room reverberation time of 0,5 sec.

Fig.2.1 - Reference Spectrum for the Transmission Loss Index R' according to DIN 4109 and ISO R-717 (in situ)

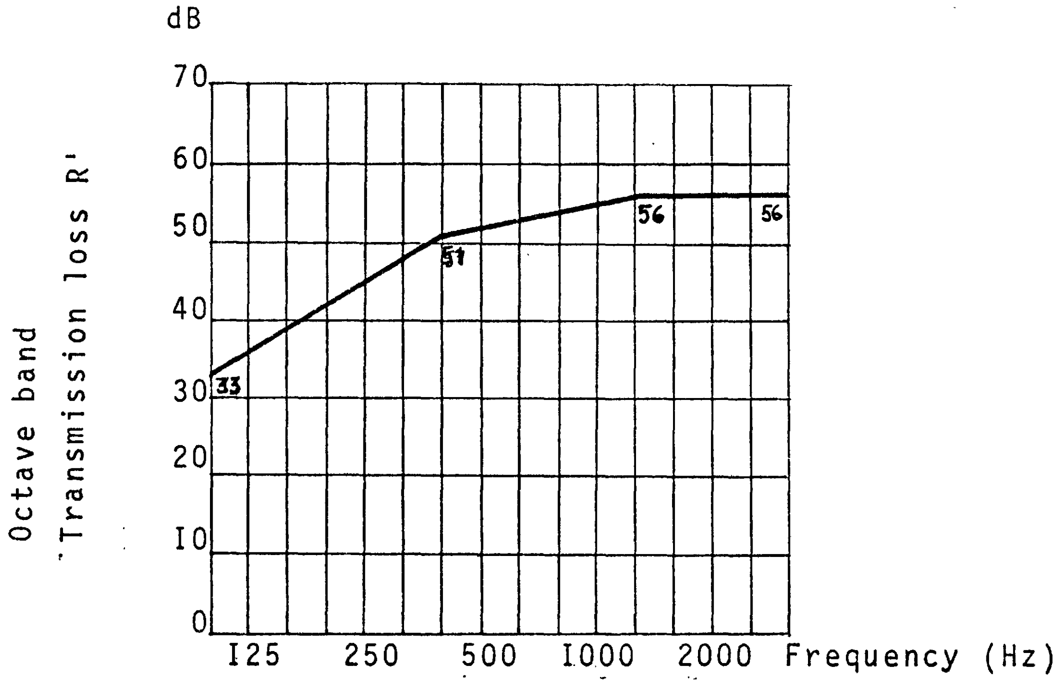
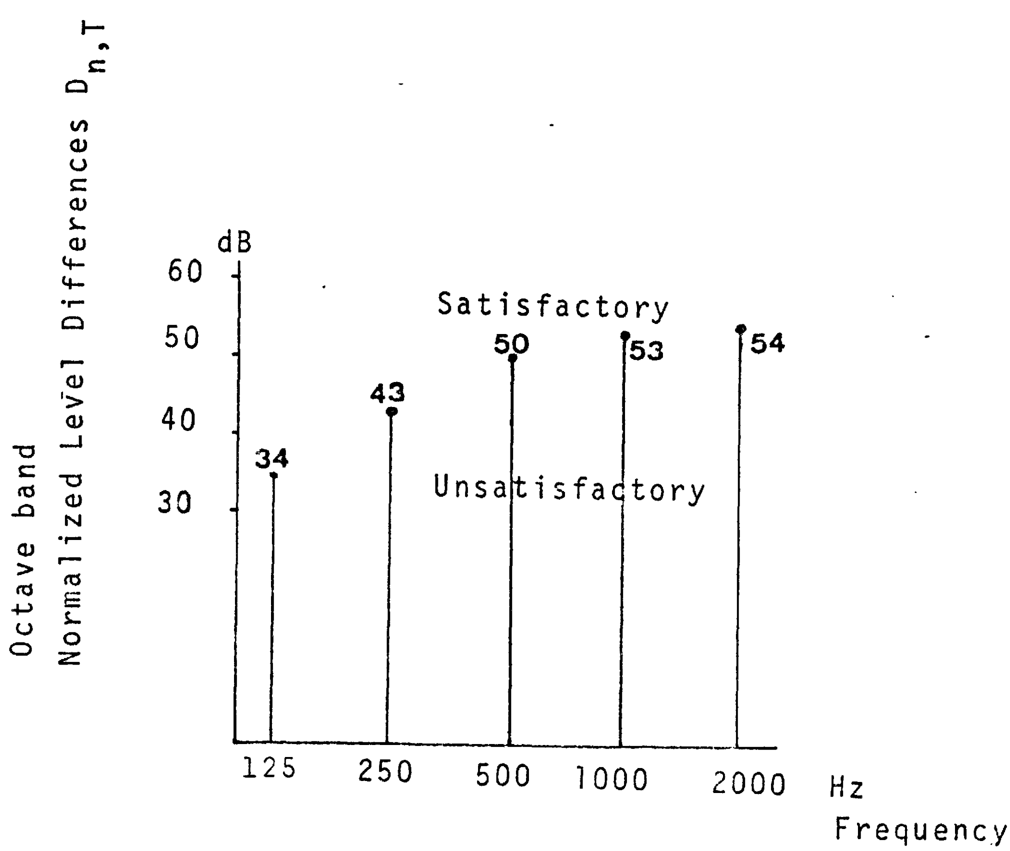


Fig.2.2 - Reference Values for the Normalized Level Difference $D_{n,T}$ according to NEN 1070.



But, in contrast, this standard has a different method for the determination of the insulation margin (Isolatie-index voor Luchtgeluid I_{lu}) : 3 indices a, b and c are computed from the difference between the measured values and criterion values and only the smallest number is kept.

The Belgian standard NBN 576.40[6] is using, except for some details, a curve that has the same shape as the reference curve used in ISO and DIN ; it does not lead to a value of the insulation margin, but uses 5 zones bounded by 5 parallel reference curves (see fig.2.3). The position of the measured spectrum of the normalized level difference D_n indicates whether a given wall satisfies a given comfort criterion.

The British[10] and the Danish[8], as the others, recommend to compare the "in situ" measurement of the normalized acoustical insulation D_n to three reference curves (see fig. 2.4 and 2.5) for apartments (grade I and II) and one corresponding to individual dwellings. A certain tolerance limit is allowed : the arithmetic sum of the negative differences with respect to the reference curve has to be under 23 dB (for 16 third-octave frequency bands, this corresponds to 1.7 dB) for the British standard and a maximum deviation of 1 dB on 16 bands is allowed for the Danish standard. Neither standard computes an insulation margin to airborne noise.*

The other trend among the standards of the European Community is led by the French. Referring to a "sociological study of the satisfaction of inhabitants of houses which have the proper characteristics to abide by the rules which are supposed to guarantee a sufficient acoustical comfort"(6), the rule is based not on a minimum insulation spectrum, but on a maximum sound pressure level not to be exceeded in a receiving room when a specific noise is produced in the emitting room. The requirements of the French standards can be summarized as follows :

* Denmark is expected to adopt in 1976 an ISO-type rating[48]

Fig.2.3- Reference Spectra and Zones for the Normalized Level Difference D_n, between Dwellings Normalized to the Belgian Standard NBN 576.40 (1966)

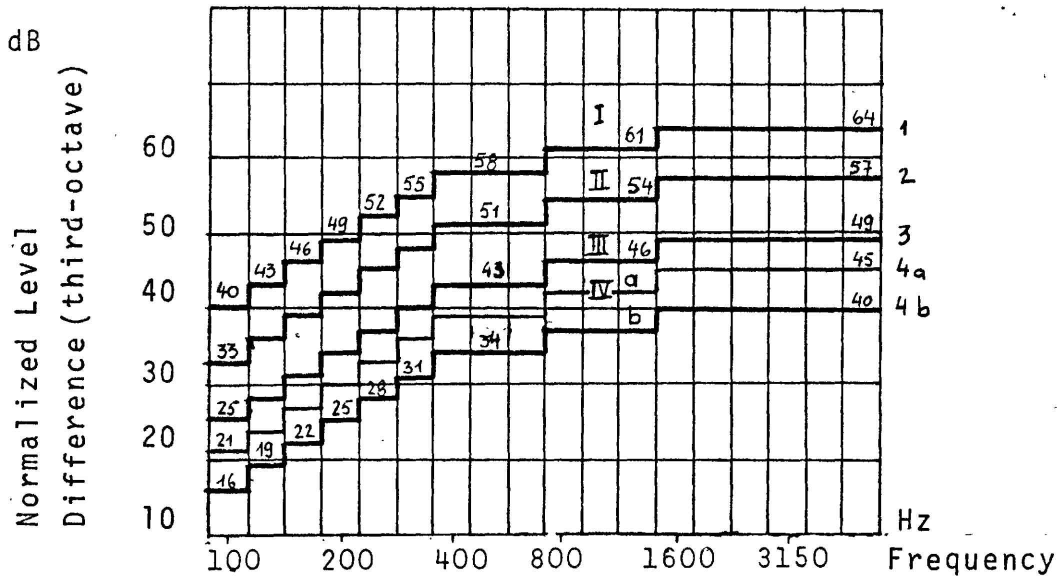


Fig.2.4- Reference Spectra for the Normalized Level Difference D_n according to the British Regulation

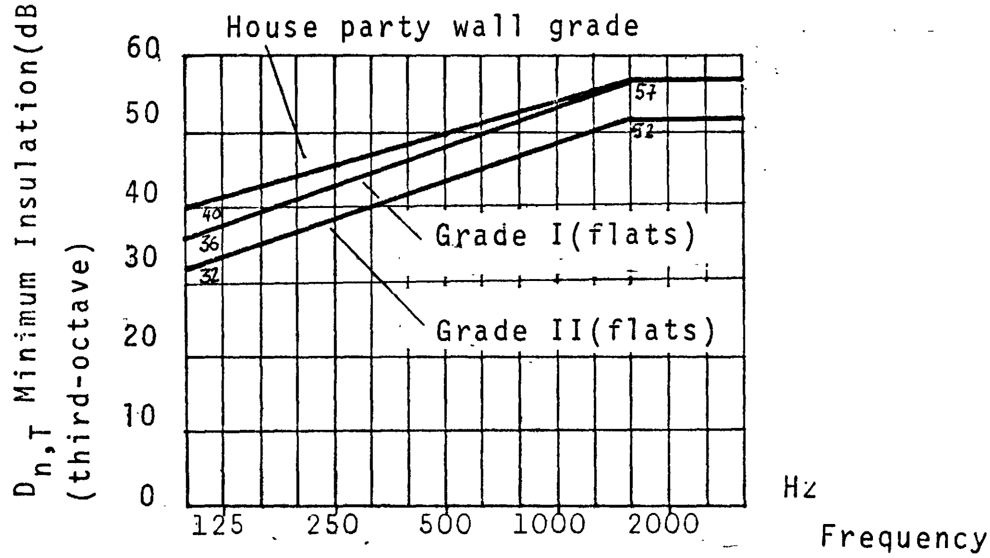
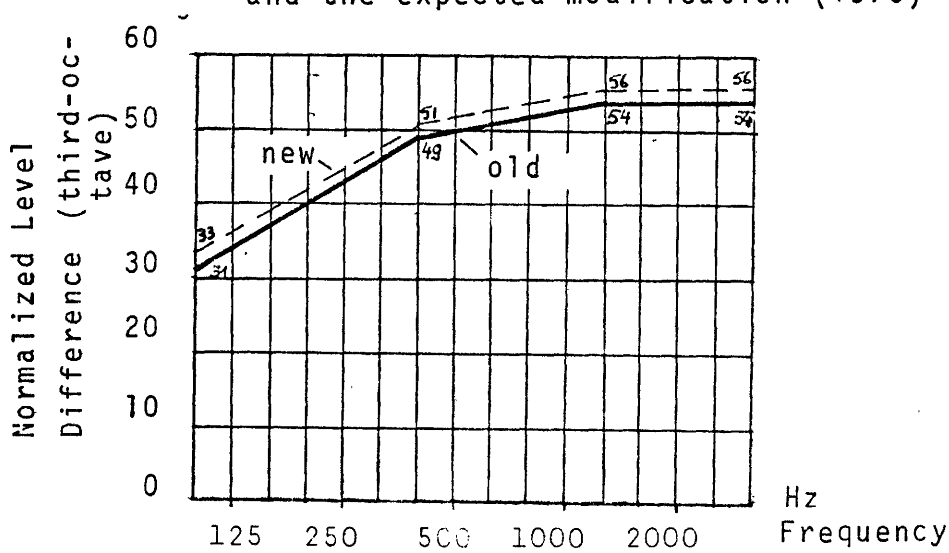


Fig.2.5 - Reference Spectrum for the Normalized Level Difference D_n according to the Danish Regulation and the expected modification (1976)



If in a room which can be considered as an emitting source of noise and located in a building used for housing, one emits a noise such that the sound pressure level for each octave band centered on the frequencies 125, 250, 500, 1000, 2000 and 4000 Hz is equal to 80 dB if this room is inhabited, 85 dB if this room is commercial or industrial, 70 dB if it is a hall used for internal circulation within the building, but is common to several dwellings, the sound pressure level of the noise transmitted into an adjacent inhabited room must not exceed 35 dB(A).

In the first analysis, this standard seems to be simple and accurately stated. It sets a required condition for a certain acoustical comfort without referring to the separating wall. It seems also to allow for a simple verification and so it would offer large advantages with respect to the other standards, if with a simple measurement in dB(A) with a precision sound level meter in the receiving room, one could check that the acoustical requirement was met and one could then avoid additional calculations.

Unfortunately, the cost and the complexity of a sound source which could independently of the characteristics of the room emit acoustical power in such a way that the sound pressure level measured in the various octave bands would be equal to 80, 85 or 70 dB, according to circumstances, raise serious difficulties. It is relatively easier to conceive sources which can put out a given acoustical power in the various octave bands that it is to find a source which must generate a given sound pressure level in rooms. The sound pressure level depends not only on the acoustical power of the source but also on the shape and on the absorption characteristics of the various walls of the room. Since this last variable depends on frequency, the sound pressure level will also vary with frequency and according to the characteristics of the room. Therefore, the measurements that have to be performed "in situ" according to the standard, that is with 80, 85 or 70 dB within an octave, require additional computations. Consequently, even though the standard and the system that is proposed by the French text are clear and precise, in practice their use requires further calculations.

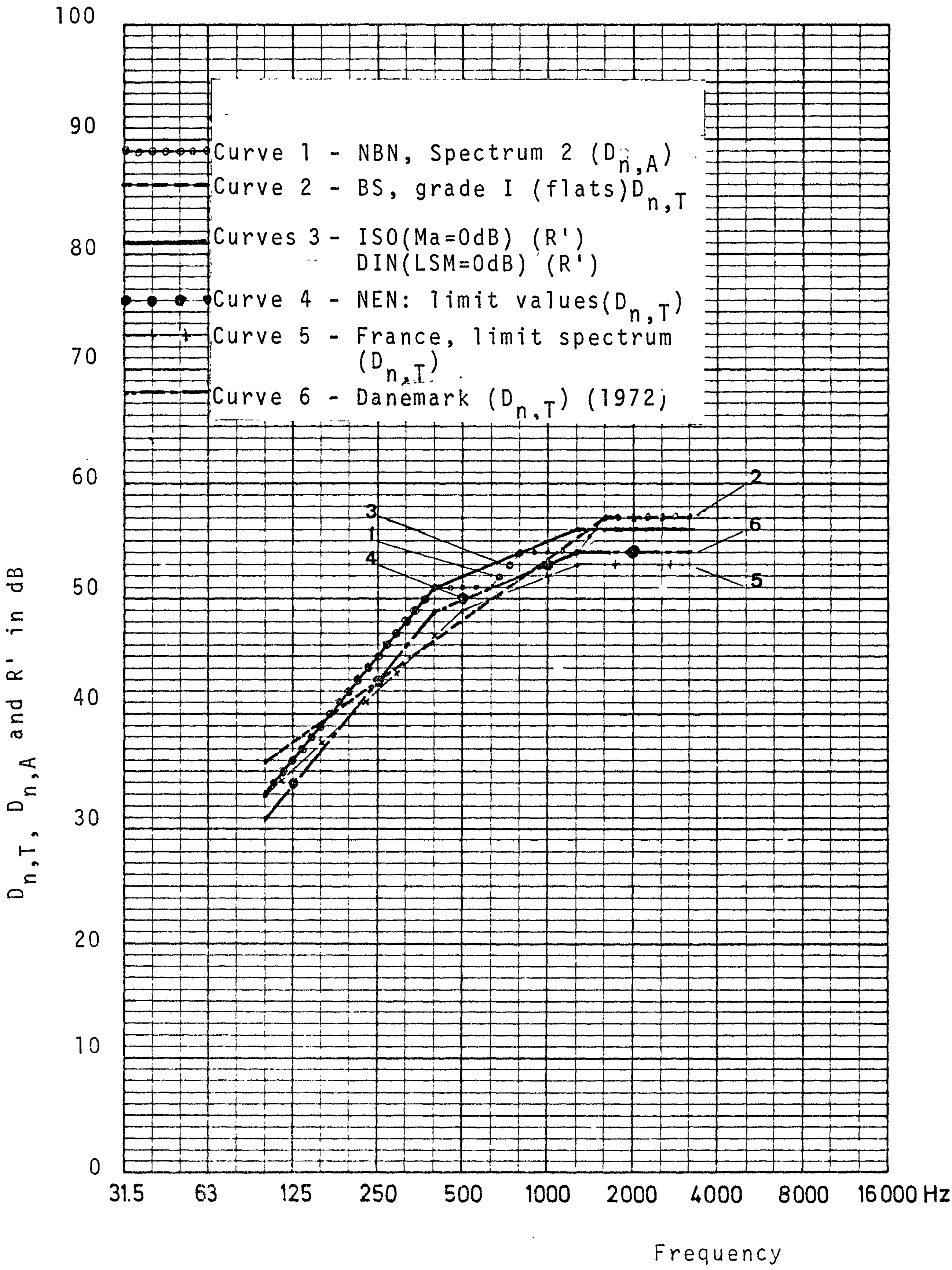
The two schools, that have been reviewed above, do not use the same language to define the acoustical comfort, but they are logical and similar. The two systems are based on the same principle, that is that if a well defined noise is produced in an emitting room, the insulation between the two rooms must be such that given sound pressure levels are not exceeded in the receiving room.

The difference between the two systems comes from the fact that the French law has used this definition as such and that the German standard DIN has used this principle to define a reference curve which represents the spectrum of the sound reduction index R' that can be prescribed to obtain a given acoustical comfort. The German approach is therefore slightly more sophisticated than that of the French system, but based on the same basic principle. One can illustrate this remark by calculating, using the text of the French standard, the values of the sound reduction index R' (assuming that R' is identical to $D_{n,T}$ in the case of an apartment of regular dimensions) for each third-octave band. One can then compare the spectrum obtained to those required by the DIN standard and the proposed reference curve of ISO.

Fig. 2.6. shows the 3 spectra next to those defined by the British, Dutch and Belgian standards which set a minimum acoustical comfort between dwellings. One will notice that the requirements for acoustical comfort are close throughout the Community.

In conclusion, the indices that are most suitable for a classification of housing according to acoustical comfort are the insulation margin Ma or the airborne sound insulation index Ia, because of their wide use. The use of the insulation margin Ma or of the airborne sound insulation index Ia raises however a problem. If Ma and Ia are expected to remain the same independently of the choice of octaves or third-octaves, the ISO definition of Ma has to be altered. The value obtained for the margin Ma is not the same if it is computed from normalized acoustical insulations measured in octave or third-octave bands.

Fig.2.6 - Comparison of airborne noise reference curves



As an example, ten spectra have been selected for the computation of the parameters Ia and Ma (appendix A) in octave and third-octave bands. The same calculation was performed but without taking into account the limits set by ISO for the maximum deviations (8 dB for third-octaves and 5 dB for octaves). Of this study, one concludes that :

a) the values obtained for Ma and Ia are larger if computed from third-octave band spectra than if computed from octave-band spectra.

b) If the maximum deviation rule of ISO is removed, the difference between these results decreases.

Consequently, the system that has been adopted in the following sections relative to airborne noise insulation is similar to the ISO standard, from which the maximum deviation requirements have been eliminated. It is called "Modified ISO system".*

2.2.4 - Summary

To determine the insulation against airborne noise due to human activities in housing, we propose :

- As the measurement parameter to determine the insulation against airborne noise between two units, the **Normalized Level Difference** $D_{n,T}$, defined as :

$$D_{n,T} = L_1 - L_2 + 10 \log \frac{T}{T_0} \quad \text{with } T_0 = 0{,}5 \text{ s}$$

- For the frequency bands to be used for the measurements :

- either, octave bands centered on the frequencies 125, 250, 500, 1000 and 2000 Hz whenever the measurement is used to control on the site itself whether the requirements are met.

* As a matter of fact, the maximum unfavourable deviation rule should be dropped in the next revision of the standards.

- or, in third-octave bands centered on frequencies between 100 and 3150 Hz when a finer analysis of the insulation against airborne noise between two units is required.

- As the index describing acoustical comfort : the **Airborne Insulation Margin Ma** or the **Airborne Sound lation Index** as defined by ISO R 717 based on the reference curve described in that norm. We propose, however, in order to simplify the use of this rule to abandon the article described in A.1, i.e. not to limit the maximum deviation from the reference curve in any band.

2.3 - Isolation Against Impact Noise

2.3.1 - Measurement Parameter

In the area of isolation against impact noises that is of the noises radiated for instance by the impact of foot-steps, of chair movements, of the shocks of objetcs falling on the floor, in an adjacent room, the standards in use in the various countries of the European Community all refer to the normalized impact noise level L_n as defined by the ISO standard R 717-1968 (E) (12) by the following formulas:

$$L_{n,A} = L + 10 \log \frac{A_o}{A} \tag{16}$$

which is used also in DIN, NBN and :

$$L_{n,T} = L - 10 \log \frac{T}{T_o} \tag{17}$$

which is used in France, Great Britain , Denmark and the Netherlands. In these formula :

- L is the average octave-band sound pressure level measured in the receiving room in dB
- A is the equivalent absorption area measured in the receiving room in m^2
- T is the reverberation time of the receiving room in seconds

A_0 is the reference equivalent absorption area equal to $10m^2$

T_0 is the reference reverberation time equal to 0,5 sec.

The sound pressure level is measured in octave bands or third-octave bands and at several points of the room, when the floor of an adjacent unit is hit by the hammer of a standardized tapping machine, which is defined almost identically in all the countries of the European Community (see ISO R 140)[24]. Since the method used to generate the acoustic field and the definition of the measurement parameter for the transmission of impact noise are defined and are the same in all the countries of interest, the comfort parameters based on actual measurements "in situ" and which refer to the acoustical comfort will be analysed.

2.3.2 - Frequency Bands to be used for the Measurements

As was the case for the isolation against airborne noise, some countries have chosen octave bands, some others third-octave bands. However, it seems preferable to perform the measurement in octave bands for all the cases where a control of the acoustical quality in a building has to be performed "in situ" and to perform a finer analysis in third-octave bands only when a more detailed investigation of the isolation against impact noise is required.

2.3.3 - Acoustical Comfort Parameter

In this area, the standards used in the European Community again diverge in a way similar to the standards used in the area of isolation against airborne noise. There are two groups :

- one, with the Dutch, British, German, Belgian, Danish standards and ISO recommendations
- the other one, represented by the French standard

The first group requires a comparison of the measured spectrum of the normalized sound pressure level due to impact noise to a reference curve*. This curve was derived from the performance of a certain type of construction empirically proved in the past to provide sufficient acoustical comfort and which takes into account the greater sensitivity of the ear to frequencies above 1000 Hz.

In a similar manner to what was done for airborne noise, one computes an Impact Protection Margin M_i for the ISO standard and TSM (Trittschallschutzmass) for the German DIN standard, which is then compared to values related to the requirements for a given acoustical comfort. These impact protection margins are computed in a manner similar to the airborne noise insulation margins : a maximum average deviation which is equal to 2 dB for the ISO and DIN normalized standards (see fig.2.7), a combination of the measured deviations for the octave bands centered on 125, 250, 500, 1000 and 2000 Hz for the Dutch standards NEN 1070 (see fig. 2.8), a network of parallel curves which define zones of acoustical comfort for the standard NBN 576.40 (see fig. 2.9), and finally a simple comparison with a reference curve without calculation of an insulation margin for the British and the Danish standards (see fig.2.10 and 2.11).

As far as the French standard is concerned, the use of a reference spectrum to be compared with the measured spectrum is avoided : a limit to the total sound pressure level in dB(A) is set for the case when drops, knocks or movements of objects or persons generate on the floor impacts similar to the intensity and rythms of those which are described in the standard NF S 31002 (that is the standard of the tapping machine). Again as was done for insulation against airborne noises, the French system requires that, once the sound pressure level has been measured in octave bands ("in situ" measurement) or in third-octave bands (laboratory measurement) and that the effect of the reverberation time of the receiving room on the measured value has been taken into account,

* Note that the shape of the Dutch curve is very different from the others.

Fig.2.7 - Reference Spectra for the Normalized Impact Sound Level L_n according to DIN 4109 (August 1962) and ISO R 717 per Octave Bands

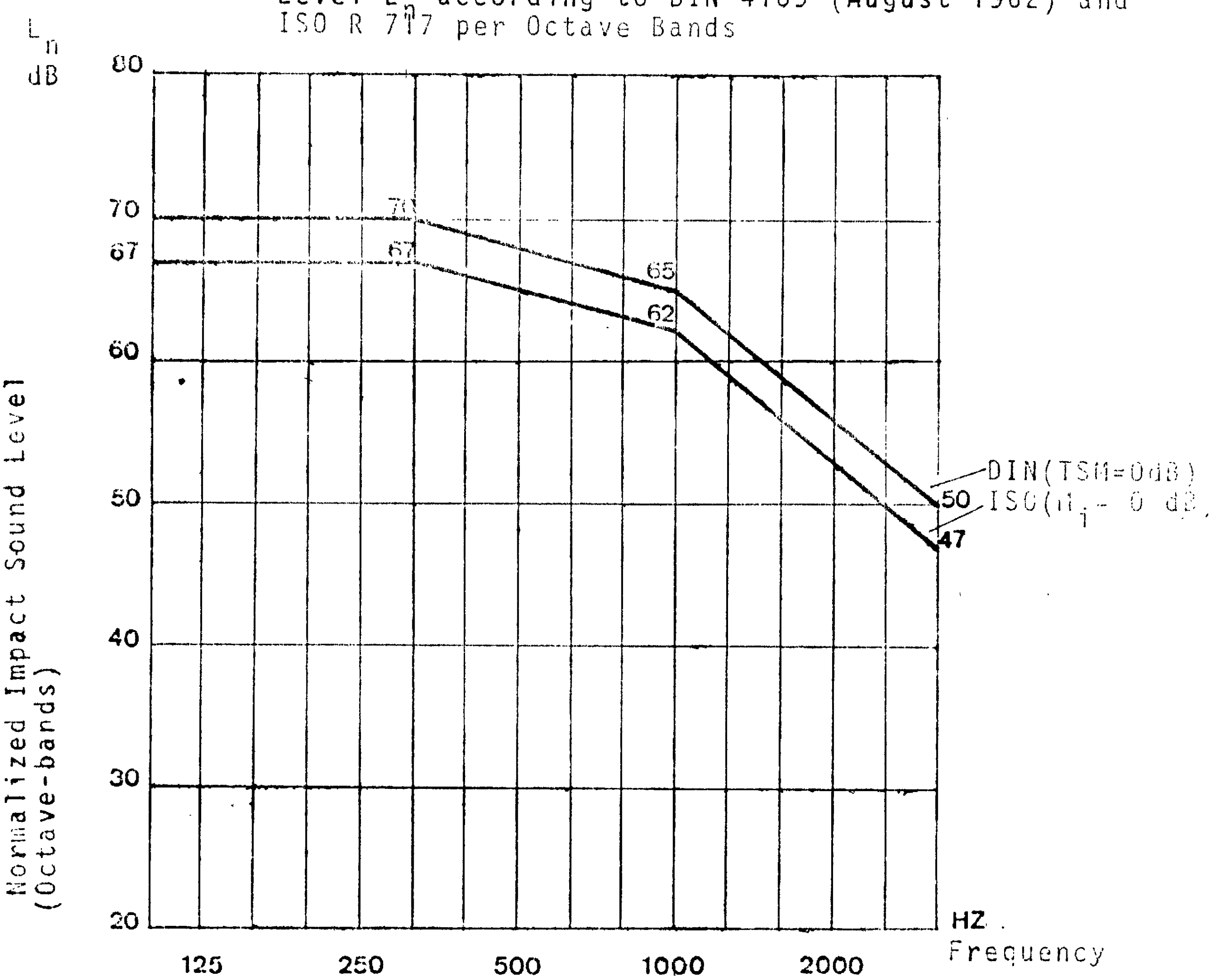


Fig. 2.8 - Reference Values for the Normalized Impact Sound Level L_n according to NEN 1070 per Octave Bands

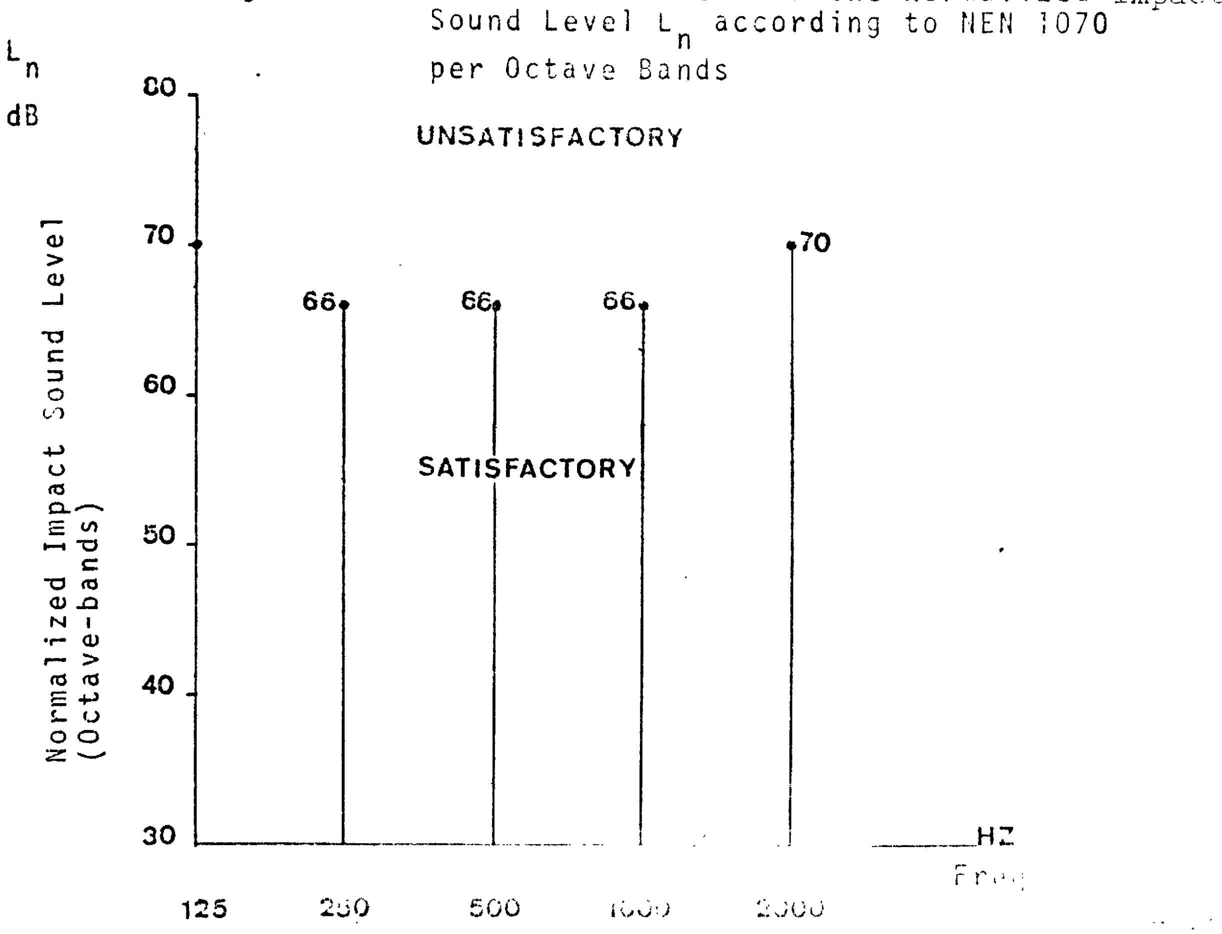


Fig. 2. 9 - Reference Spectra and Zones for the Normalized Impact Sound Level according to NBN 576-40

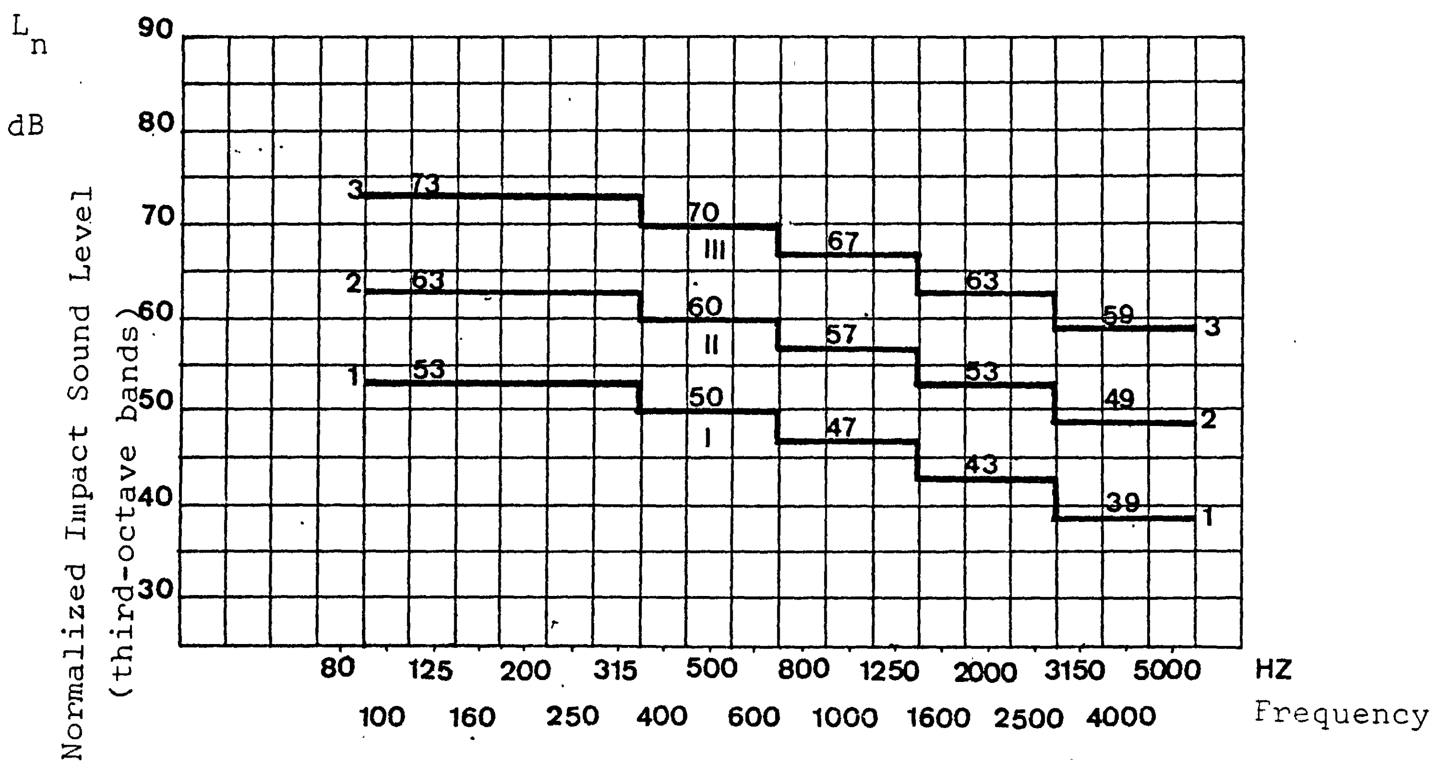


Fig. 2.10 - Reference Spectra for the Normalized Impact Sound level L_n according to the British Regulation per Octave Bands

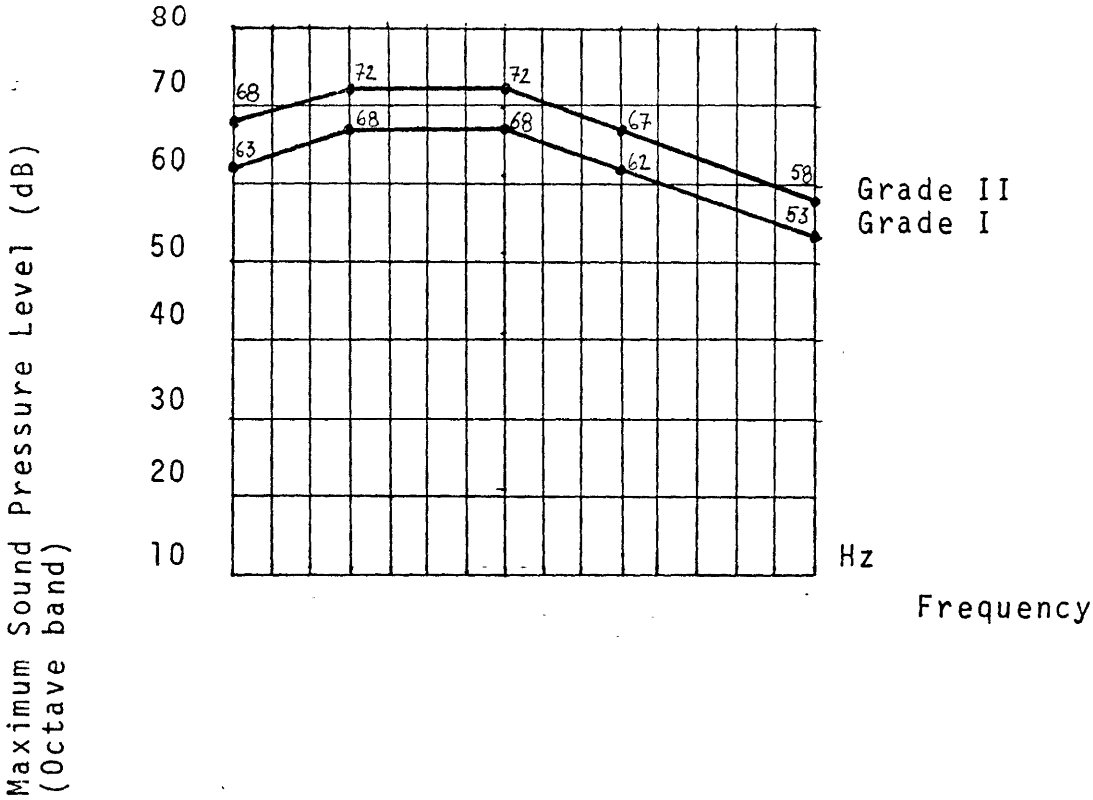
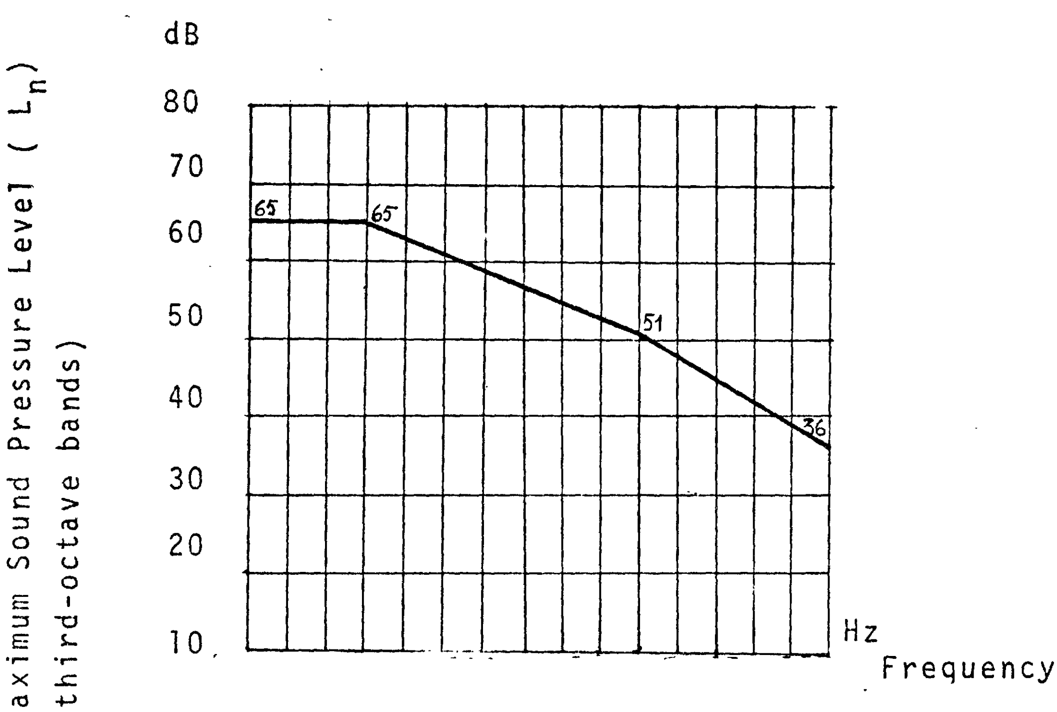


Fig. 2.11 - Reference Spectrum for the Normalized Impact Sound Level L_n according to the Danish Regulation per 1/3 octave



the spectrum that is thus obtained is A-weighted and the energy sum is performed to determine a total level in dB(A). We have, as was done in section 2.2., compared the different requirements on isolation against impact noise in the various countries of the European Community. These reference curves are reproduced in fig. 2.12, where :

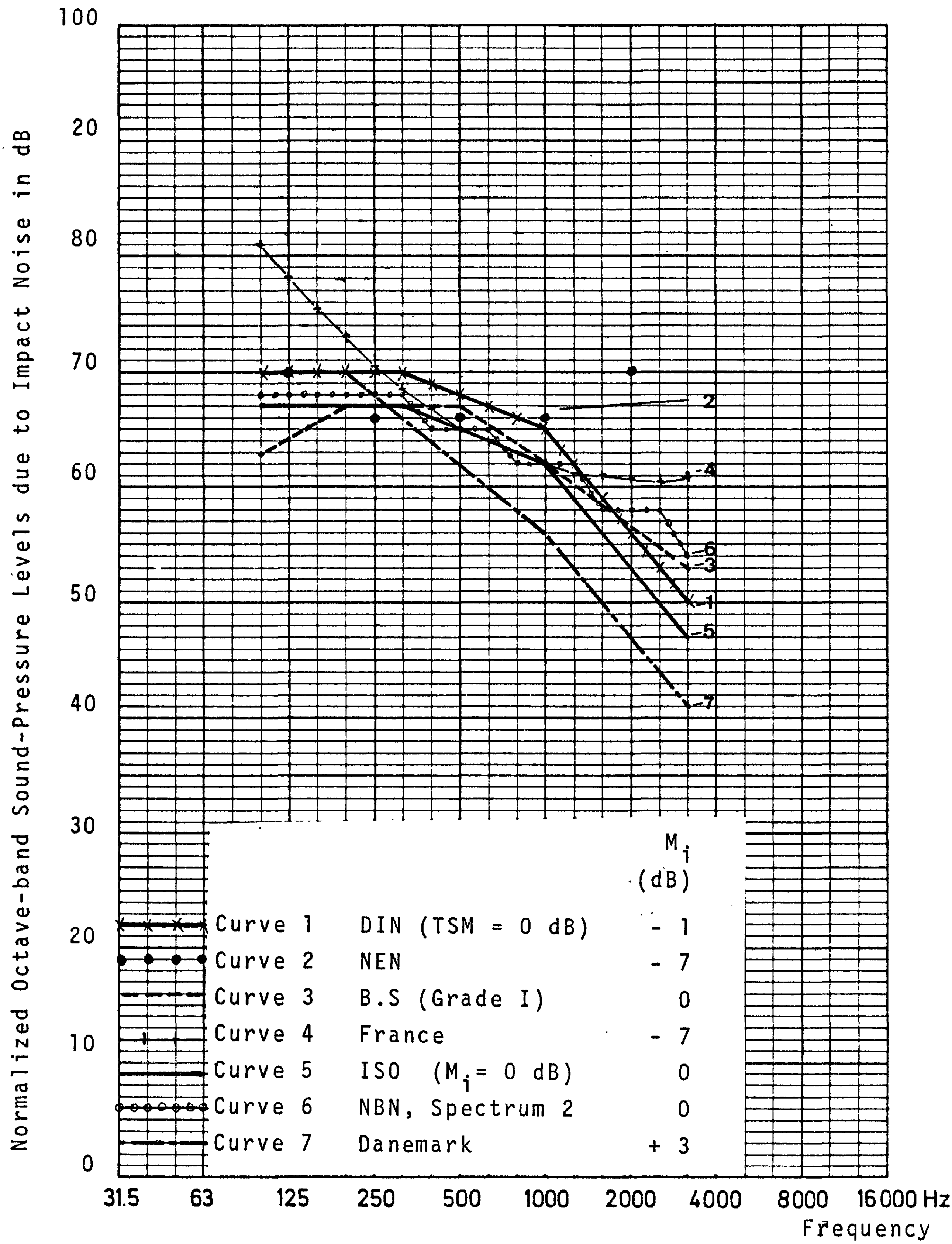
curve n° 1 : DIN 4109 (TSM = ± 0 dB)
curve n° 2 : NEN 1070
curve n° 3 : BS (grade I)
curve n° 4 : French Regulation (70 dB(A))
curve n° 5 : ISO R 717-1968 (E)
curve n° 6 : NBN (curve 2)
curve n° 7 : Danish requirements

These reference curves all correspond, except for the ISO standard, to the minimum requirement between dwelling units. ISO gives only a reference curve without setting comfort requirements.

As far as the requirements of the French standard are concerned, we have drawn the maximum of the curves that correspond to a total A-weighted level of 70 dB(A) and beyond which any other spectrum would exceed this total level. In fact, one must realize that there is an infinity of spectra that would correspond to a level of 70 dB(A).

When one computes for the various curves, the impact protection margin M_i (according to ISO), one concludes that the differences between the various values are larger than was the case for airborne noise. The maximum difference between the largest and smallest insulation margins is 10 dB (M_i = - 7 dB, according to NF and NEN and M_i = + 3 dB according to the Danish standard). The average of the various impact noise insulation margins M_l is - 1.7 dB. Another comment is in order concerning the shape of the various spectra : all the curves have approximately the same shape except those prescribed by the French and Dutch regulations, that is that they all start with an horizontal line in the low frequencies (from 100 to 200, 315 or 500 Hz) and then decrease in 2 steps (from 315 or 200 to 1000 Hz and from 1000 Hz to 3150 Hz) for the ISO and DIN standards

Fig. 2.12 - Comparison of the Normalized Maximum Spectra for Impact Noise between Dwellings



or in one step (from 500 to 3150 Hz) for the British standard or in several successive steps for the Belgian standard. The French curve increases in the low frequencies and is approximately constant in the high frequencies. This divergence in the high frequencies has no serious consequences since in this range, the acoustical energy of usual impact noise such as foot-steps, chair movements or children's games is relatively small compared to the energy at low and medium frequencies [(25)]. However, in the low frequencies this difference between the levels required in the French regulation and the other standards is important since it is in this frequency range that the acoustical energy radiated by impact is important. The maximum difference between the levels required by the French regulations and those required by the DIN 4109 standard, is :

- at 100 Hz : 14 dB
- at 125 Hz : 11 dB
- at 160 Hz : 8,5 dB
- at 200 Hz : 7 dB

The differences described above may be considered mitigated since the accuracy of the measurement of the sound pressure level L_n is quite poor at low frequencies. However, this uncertainty of measurement is not sufficient to justify completely such large numbers, particularly if one notices that the present tendency of some standards, namely German, is to be even more severe as far as impact noise is concerned. This means that the above difference is bound to increase even more.

We note also that in the case of insulation against impact noise, it does not exist, as is the case for airborne noise insulation, an equivalence between the two methods, since the quantity that is compared is not a difference of sound pressure levels but a sound pressure level defined in the two groups according to different spectra.

For the reason described above and also given in section 2.2.3, the criterion as defined in the ISO standard R 717 seems to be most adequate. However, the same reservation concerning the maximum deviation limit of 5 dB, for octave band levels, as in the case of airborne insulation, has to be made.

We note that a great deal of research is being conducted in the area of impact noise rating and that new methods should follow(34-43).

2.3.4 - Summary

To define the noise impact isolation , in the classification of housing according to acoustical comfort, the normalized impact noise sound pressure level L_n will be used. It is defined as :

$$L_n = L - 10 \log \frac{T}{T_0} \text{ with } T_0 = 0{,}5 \text{ s.} \qquad (18)$$

The frequency bands within which the measurements will be performed will be similar to those used for airborne noise that is the octave bands centered on frequencies from 125 to 2000 Hz, or the third-octave bands centered on frequencies from 100 to 3150 Hz. If third-octave band levels are obtained, before performing the comparison with the reference spectrum, one must compute the octave band levels. To determine the criterion of acoustical comfort, the impact protection margin M_i will be used or the impact sound insulation index I_i as defined by ISO R 717-1968 (E), i.e. $I_i = M_i + 65$. The maximum deviation rule of ISO of 5 dB per octave will be eliminated.

2.4.- Isolation against Outdoor Noise

The outdoor noise sources which may influence acoustical comfort inside a dwelling are the following : aircrafts, automobiles, railways, boats, industry, sports grounds, bells etc ...

Some of these sources generate sound pressure levels that vary constantly, it is the case of transportation systems. Others such as, industrial noise sources, are almost constant. It is therefore necessary to examine the variations of the sound pressure level and to choose a way to describe them.

2.4.1 - Measurement Parameter

If one draws a curve of the sound pressure level in dB(A) as a function of time, for example on a graphic level recorder, during a finite interval, one obtains a graphic representation which shows the instantaneous values of the level (see fig. 2.13). From such data, it is difficult to draw a conclusion on the annoyance due to this noise. One of the reason for this is that a graphic representation contains too much information to allow a comparison with other sources or to be used as an indication of acoustical comfort.

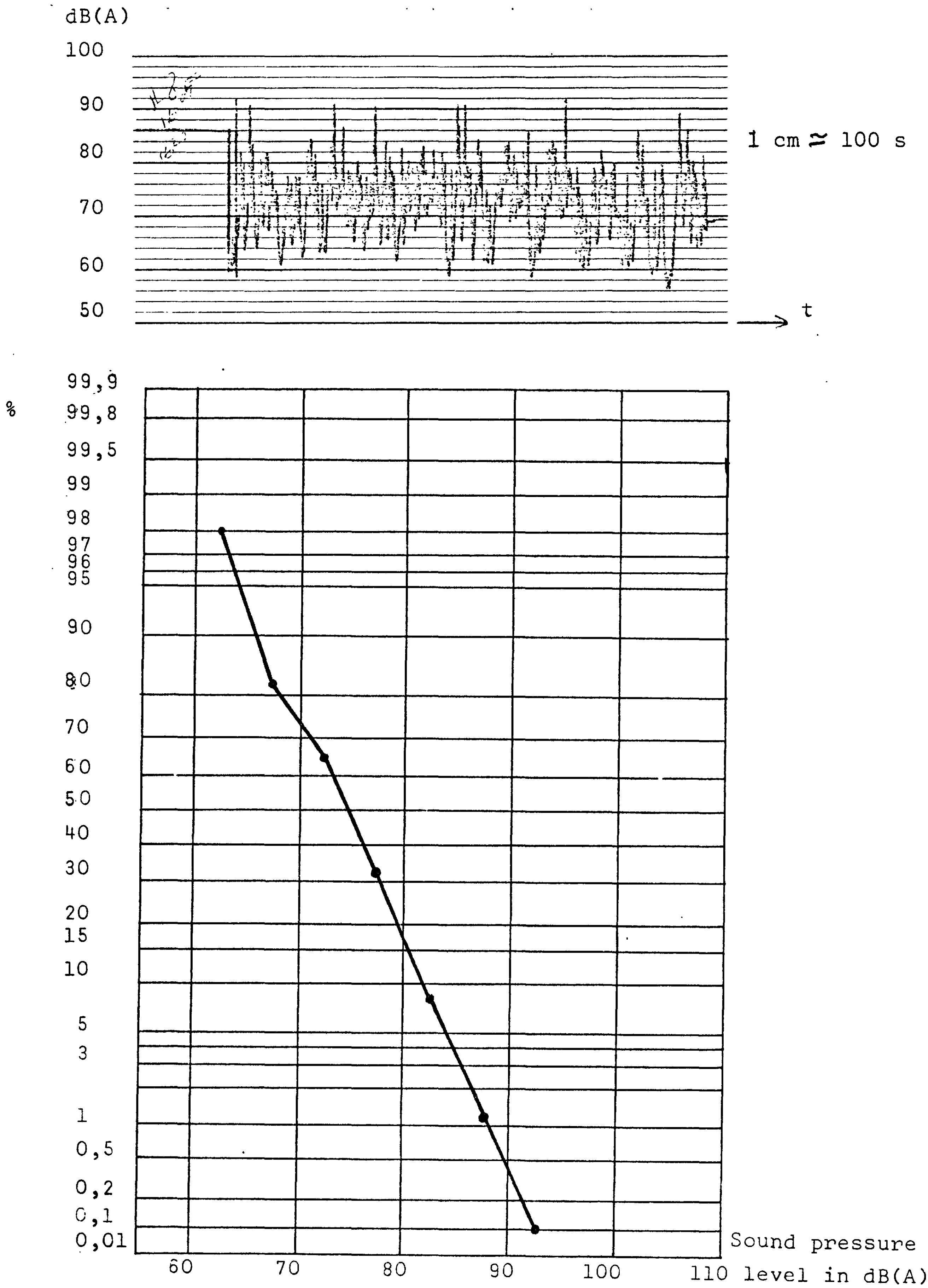
A statistical analysis of the noise may be more convenient : it consists in defining certain classes of noise levels and in determining the amount of time during which the level that has been measured remained within one of these classes. From such data, one can compute two measurement parameters :

- either the level exceeded during x% of the time or $L_{x\%}$
- or, the equivalent level L_{eq}

1. Level L_x exceeded during x% of the Time :

The level L_x is the sound pressure level in dB(A) which has been exceeded during x% of the time during which the sound level has been observed (see fig..13).

Fig. 2.13 - Typical Recording of Traffic Noise near the Roadway and Cumulative Distribution



L_{95} or L_{90} represents sound pressure levels which have been exceeded during 95% or 90% of the time respectively and they can be considered good representations of the background level

L_{50} which is the sound pressure level exceeded half of the time can be used as the median level.

L_1 which is the level exceeded 1% of the time can be used as a representation of the peak noise levels which are present during the measurement period.

$L_{0.1}$ can be used to describe noise levels which are very rarely exceeded (peak levels).

Various countries have used in the past L_{10} and L_{50} but the trend is to replace these quantities with L_{eq} and sometimes, as in some recommendations[15] in Germany with the level L_1.

Before deciding whether such parameters may be used to describe the acoustical comfort in buildings, it is important to understand them. A report by Schreiber (17) has analysed some of the problems that the use of statistical levels may generate :

a) the single point of the curve representing $L_{x\%}$ as a function of time gives little information on the ambient noise level. For instance, if the traffic is very light L_{50} and L_{10} , and even in some cases L_1 , are all equal to the background noise level. Assume a background level of 45 dB(A) during night-time and assume that each automobile that drives-by affects this level during only 10 seconds. During the eight night-time hours, that is 28 800 seconds, 29 vehicles might drive-by without influencing at all the L_1 level. Therefore, in that case :

$$L_{95} = L_{50} = L_{10} = L_1 = 45 \text{ dB(A)} \tag{19}$$

The L_{50} level would increase only if 180 vehicles drive-by every hour, under the above conditions.

b) the maximum levels have little or no influence on the high percentage levels

L_{50} = 45 dB(A) indicates only that the level 45 dB(A) has been exceeded for 50% of the time, but the actual value of the levels larger than L_{50} has no influence on L_{50}. The mathematics which have to be used with L_x levels can be quite intricate in the case when the distribution of levels is not gaussian.

c) the levels L_x cannot in general be added. For example, the two values of L_{50} corresponding to two noises cannot be added to obtain the L_{50} value that would result from the combined noise. Additional information on the distributions is needed.

2. Equivalent level L_{eq}

The equivalent level of noise which varies during an observation time T is the sound pressure level that would be measured if all the acoustical energy was uniformly distributed during this time T.

L_{eq} is defined as follows

$$L_{eq} = 10 \log \left[\frac{1}{T} \int_0^T 10^{0.1\, L_{i(t)}} dt \right] \qquad (20)$$

Where :

L_{eq} is the equivalent level in dB(A),

T is the time interval during which the phenomenon has been observed in seconds. The reference time often used is 1 hour.

$L_{i(t)}$ is the sound pressure level in dB(A),

dt the time interval in seconds.

The formula (20) can also be rewritten :

$$L_{eq} = 10 \log \left[\sum_i \frac{T_i}{T} \times 10^{0,1 \times L_i} \right]$$

T_i is the duration of the level L_i.

We notice that if the L_i level is constant, then :

$$L_{eq} = L_i = \text{constant} \qquad (21)$$

The use of the equivalent level is normalized in the Federal Republic of Germany[18] and recommended[19] in Denmark and by the ISO standard R 1996[20]. The advantages of this parameter are :

a) it is sensitive to all the recorded levels during the total time interval T.

b) the equivalent level is affected by the number of noise events as well as by their levels

c) if n sources with different equivalent levels L_j exist simultaneously, then the total level will be :

$$L = \sum_{j=1} 10^{0,1 L_j} \qquad (22)$$

d) It correlates relatively well with subjective judgement

We have to note however, that the equivalent levels L_{eq} is a very weak picture of events of short duration. Thus, it may be necessary to use another quantity more suitable for this purpose, for instance L_1 as proposed by the German recommendation VDI 2719[15]. However, this quantity is very difficult to measure in a short time interval.

3. Choice of a Measurement Parameter

The use of the equivalent level is recommended as a quantity which is representative of the noise and is also very easy to use since it does not require any complicated mathematics. Its use is now becoming commonplace in the countries of the Community as well as outside of Europe. To evaluate peak levels, it would be premature to recommend a quantity such as L_1, which needs to be investigated further. Instead, when setting criteria, a maximum value, referred to L_{eq}, will be set which it will not be permitted to exceed, even for short duration events. Then, no measurement or predictions of statistical levels would be necessary.

2.4.2 - Acoustical Comfort Parameter

According to the type of sources and to the country, different parameters have been used.

The main ones are :

a) a limit of the statistical level L_x or of a combination of levels L_x

b) a limit to the equivalent level L_{eq}

c) a maximum value for a combination of equivalent levels L_{eq} and statistical levels L_x.

Let us analyse these cases in more detail :

In the Federal Republic of Germany, no standard and no law set a limit to the intrusion of exterior noise within a building used for housing. Such limits, however, are being considered in a standard(21) which could define the acoustical quality required for the skin of a building so that it can be considered a sufficient protection against outside noise sources. The comfort will be determined by an equivalent level (Mittelungspegel L_{Am}) which will be a limit not to be exceeded within a bedroom or a living-room.

This same system is already used in a VDI recommendation in which are set the maximum values of the equivalent level L_{eq} and of the statistical level L_1. L_1 is used together with the equivalent level so that the short duration noises can be considered which during the night may be responsible for annoyance. In his analysis, Schreiber(17) indicates that it would be more logical to use $L_{0.1}$ instead of L_1, but that this quantity would be costly to measure with a narrow confidence interval. He proposes therefore to do away with this statistical level L_x but to use instead a maximum level which would be measured for a standardized heavy truck or for a standardized automobile driving-by near the measuring point.

In Belgium, this problem has not been considered yet.

In Denmark, there is no regulation or standard on this particular problem. There is however a recommendation[19] which sets the limit for the intrusion of an exterior noise within a dwelling and which uses an equivalent level identical to the German quantity L_{Am}.

France, as far as it is concerned, uses the L_{50} level, that is the level exceeded 50% of the time to describe the noise and the annoyance due to traffic. As we noted earlier, this descriptor tends however to be replaced by the equivalent level L_{eq}[22]. We note also that, in France, laws which limit the intrusion of outside noises in buildings used as housing are being prepared. France has also homologated the standard NF S 31-010[45] which contains most of the ISO R 1996 recommendation. However, it does not have force of law since it remains a recommendation.

In Great Britain[23], the limit on noise intrusion is related to an L_{10} level or the level exceeded 10% of the time which is measured for 18 hours or to CNL (corrected noise level)for industrial noise and the NNI (Noise and Number Index) for aircraft noise. These standards are different from the recommendations of other countries of the European Community, since they set a noise limit outside housing buildings.

The Netherlands[11] in their standard NEN 1070 choose a measurement parameter and a comfort criterion which are both expressed as equivalent levels L_{eq}.

The ISO recommendation 1996[20] proposes an acoustical comfort parameter based on the equivalent level L_{eq} : it is called the rating sound level L_r and is equal to the sum of the measured equivalent level and corrections depending upon the specific characteristics of the noise (the peak value of the measured sound pressure level, the presence of pure tones, the duration of a sound with respect to the relevant time period), the time of the day (day, evening, night) and to the type of residential area.

The rating sound level L_r is meant to be used for outdoor noise, about three to four meters away from the walls of the dwelling. However, the same parameter can be used to define the acoustical comfort inside dwellings or houses, if the values corresponding to outdoor noise are reduced by 10 dB(A) if the windows are opened and 20 dB(A) if they are shut. This possibility has not been retained by the French norm NF S 31-010 (45).

In conclusion, we propose the use of a parameter which is based on the hourly equivalent level (L_{eq}) measured in the main rooms of a dwelling. It should be corrected according to the noise characteristics and the time of the day as shown in the following table 2.1.

Table 2.1 - Corrections for Measured L_{eq} and criterion

<u>Measured L_{eq}</u> *	
1) Impulse Noise Correction	+ 5 dB(A)
2) Audible pure tone	+ 5 dB(A)
<u>Noise Criterion</u>	
1) daytime (7^{00} to 22^{00})	0 dB(A)
2) nightime (22^{00} to 7^{00})	-10 dB(A)

The measured and corrected values of L_{eq} will be compared to the noise criterion which will depend on the class of acoustical comfort. In order to take into account the unexpected peak noise levels that occur for instance when a very noisy car or lorry passes by, it will be allowed for the limit to be exceeded by as much as 10 dB(A) for exceptional events.

* The corrected value is L_{eq} + 5 when the noise is impulsive or when it contains audible tone components or both.

2.4.3 - Summary

The parameter used to measure the intrusion of outdoor noise in a dwelling is the hourly equivalent level L_{eq}. The parameter choosen to define the acoustical comfort with respect to outdoor noise sources is the equivalent noise level L_{eq} corrected for the characteristics of the noise and the period of the day as described in section 2.4.2.

2.5 - Isolation against Noise from Common or Individual Equipment

In dwellings, other noise sources exist besides those directly related to human activity or outdoor sources. There are due to :

1) Common equipment : heating, garbage chutes, air moving systems, electrical relays, laundry, washing equipment, hot or cold water installations etc .

2) Individual equipment which consists in general of household applicances or taps.

Most of the noise sources have a constant level over some period of time (heating, air-moving systems, appliances) while others emit impulsive sounds (relays, lifts, bells, garbage chutes).

2.5.1 - Measurement Parameter

The measurement parameter used throughout the European Community is the A-weighted sound pressure level measured in the living-room or in the bed-room of a flat or a house when one element of the collective or individual equipment is in service. When the radiated noise is of an impulsive nature, then the maximum A-weighted sound pressure level is generally considered. When the noise is impulsive or when it contains audible tone components, or both, 5 dB are added to the average A-weighted sound pressure level measured with a precision sound level meter, on the "fast" setting.

2.5.2 - Acoustical Comfort Parameter

Generally, the parameter used is the A-weighted sound pressure level. It sets a limit beyond which noise sources which emit an almost constant noise level are deemed to become annoying.

2.5.3 - Summary

The measurement parameter and the acoustical comfort parameter for insulation against common or individual equipment noise is the A-weighted sound pressure level measured with a precision sound level meter, with a 5 dB correction for impulsive sound or pure tone components, or both.

2.6 - Isolation Against Vibrations and Structure-Borne Sound

As we have noted in the introduction (see 2.1), there is no standard as such which sets a limit to vibrations or shocks to which human beings or buildings are exposed. We note,however, that the effects of structure-borne sound have been already considered implicitely since, when setting standards in dB(A) (section 2.2.2.) on the insulation against noise from building equipment such as lifts, heating and so on, or against outside sources, the sound pressure level which has been chosen as a limit in a room describes, not only the airborne transmission between the source and the receiving room, but also the solid-borne sound propagation through the walls of the receiving room which is automatically radiated as airborne acoustical energy within the room. Therefore, the sound pressure level that is set in the standards is the sum of the airborne noise and of the solid-borne noise. Beyond the above remark, there is no specific standard in this field. Therefore, vibrations and shocks will not be considered in the following classification to define the acoustical quality of housing even though they may be relevant. When enough information is available, it will be a simple matter to complete the following classification with appropriate criteria.

3 - CLASSIFICATION OF ACOUSTICAL CRITERIA

3.1 - Introduction

Since the parameters to be used in determining acoustical comfort of housing have been chosen, the present chapter will investigate the various methods and requirements in use in the European Community member nations. As noted earlier, these requirements are described in terms of different measurement and acoustical comfort parameters. Therefore, they have been transposed into a common system, derived from chapter 2 and summarized in section 3.2. The technicalities of the conversions are investigated in appendix B. The results obtained using the various national methods have been compared in section 3.3. Then, the classes of acoustical comfort are described in section 3.4. and an overall classification system is established.

3.2 - A Summary of Relevant Parameters

The following parameters have been selected to describe acoustical comfort.

- Airborne noise insulation of walls:

  I_a (in dB) Airborne sound insulation index

- Impact noise insulation of floors :

  I_i (in dB) Impact sound insulation index

- Insulation against outdoor airborne noise :

L_{eq} [in dB(A)]	- The equivalent level L_{eq}/hour is measured inside a room and expressed in dB(A) - The maximum value of the measured sound pressure level should not exceed a value equal to L_{eq}+ 10 dB(A)

- Insulation against the noise of individual and collective equipment

L_p [in dB(A)]	- A-weighted sound pressure level measured in the receiving room

3.3 - Investigation and Unification of the National Requirements in Europe

Using the language summarized in section 3.2 , the requirements of the various nations member of the European Community, as far as acoustical comfort is concerned, can be evaluated and compared. The deviations between the different methods can then be computed.

For each category of acoustical requirement affecting comfort, a table is presented which shows, for each country, a number which is the evaluation of the national requirements in the system of parameters chosen in chapter 2. The numbers in brackets correspond to the values obtained using the respective national standards which usually correspond to a better acoustical comfort than the one resulting from the national requirements.

3.3.1 - Insulation between Dwellings

The translation of the various national requirements into the chosen system of parameters is sometimes critical, as far as the insulation against airborne or impact noise between dwellings is concerned. Even though most of the national procedures are very similar, there remains small differences. For each standard, these fine points were examined and choices had to be made : the motivations behind these choices can be found in Appendix B. In the following sections, only the end results are given.

3.3.1.1 - Insulation against Airborne Noise

Table 3.1 gives the values of the Airborne Sound Insulation Index Ia in dB*

Table 3.1 - Airborne Sound Insulation Index Ia for Various National Requirements

	B	D	DK	F	GB	NL	Average
Between flats	51	52 (55)	51	47-50 (53-58)	51	50	50,8
Between houses	-	55	54	-	52	-	53,7
Trend	-	-	-	>51	-		

* See references 6 to 12

It should be noted that the value of 47 dB derived from the French laws concerns minor rooms such as kitchen, bathroom and toilet; it is not taken into account in the average.

The trend that is shown in Table 3.1, for France, is not derived from an offical draft but only from the views of a number of experts.

3.3.1.2 - Insulation against Impact Noise

Table 3.2 gives the values of the impact insulation Index I_i in dB for octave-band normalized levels L_n.

Table 3.2 : Impact Sound Insulation for Various National Requirements

	B	D	DK	F	GB	NL	Average
Between dwellings	55, 65, 75	63-66	62	72	65	72	66
Trend	-	58					

The Belgian code includes three cases according to the type of room : only the value of 65 dB, required for main rooms has been taken into account in the mean.

The German standard DIN 4109 considers two values : the first (63 dB) which is the most severe, is required for a period of two years after the building is completed. The second value (66 dB) corresponds to the end of the two year period during which the insulation materials settle under load. This last number was entered in the average.

Since the French system cannot be readily converted into the method chosen here, the value of I_i given is only an approximation.

3.3.2 - Insulation between a Dwelling and common circulation spaces

The computation of the indices I_a and I_i, according to section 3.3.1, is explained in depth in Appendix B.

3.3.2.1 - Airborne Noise Insulation

Table 3.3. - Airborne Sound Insulation for Various National Requirements

E	D	DK	F	GB	NL	AVERAGE (°)
58,51,43	52-55	51	40 43 -46	51	50	51

(°) computed for B values, lowest D value, DK and GB

The Belgian code sets different values for bedrooms (58 dB), living-rooms and dining-rooms (51 dB) and other rooms (43 dB). The 55 dB value imposed to the index I_a in the German DIN standard applies to floors separating a dwelling from a collective garage and its access ramps.

It should be noted that, except for the French standard, all the numbers quoted in table 3.3., including the mean, apply to separation walls without doors. The French law, on the contrary, considers walls and doors together. The Danish rules stress that the entrance doors to a flat must provide an insulation such that the mean sound reduction R'_m measured "in situ" is equal to 30 dB.

3.3.2.2 - Impact Noise Insulation

Table 3.4 - Impact Sound Insulation Indices between a Dwelling and common Circulation Spaces (I_i in dB)

B	D	DK	F	GB	NL	Average
-	63	56	-	66	72	61,7

The value quoted for the German requirements corresponds to a recently completed construction. The requirement is somewhat less stringent (66 dB) after three years.

3.3.3 - Insulation between a Dwelling and a Commercial, Industrial or Workshop area

3.3.3.1 - Airborne Noise Insulation

Table 3.5. : Airborne Sound Insulation Between a Dwelling and a Commercial, Industrial or Workshop Area

B	D	DK	F	GB	NL	Average
-	62	*	55 (58)	-	-	58.5

* In Denmark, these limits are set by local legislation

3.3.3.2 - Impact Noise Insulation

Table 3.6 - Impact Sound Insulation Indices between a Dwelling and a Commercial, Industrial or Workshop Area

B	D	DK	F	GB	NL	Average
-	48	⁑	-	-	-	-

⁑ In Denmark, these limits are set by local legislation

3.3.4 - Insulation of a Dwelling against Outdoor Noise

Very few legal rules exist in the area of insulation of dwellings against outdoor noise, in the countries of interest . Some laws are being prepared which will set a limit to the "immission" of outdoor noise within homes. In Germany, a recommendation[15] VDI 2719 sets limits to the equivalent level L_{eq} and the average statistical level L_1 for different times of the day and for various types of zones. Table 3.7 gives the corresponding values of L_{eq}.

Table 3.7 - Limits for L_{eq} according to VDI 2719 (in dB(A))

	Normal Zone (b)	Quiet Zone (a)
Living-room 7am to 10 pm	35-40	30-35
Bedroom 10 pm to 7 am	30-35	25-30

(a) Quiet zone : residential areas, rural areas, hospital, cure and rest areas

(b) Normal zone : all other areas

The values recommended for the statistical level L_1 are 10 dB above the values quoted for L_{eq} in table 3.7. Note that the upcoming German standardization in this area will be derived from these recommended values.

In France, beyond the requirements of the law, some stiffer rules have been drawn which lead to an improved acoustical comfort, which is certified by an official certificate called "Label Acoustique". Among these rules, some set the insulation characteristics of the façade according to three zones :

Zone I : $L_{eq} > 73$ dB(A)
Zone II: $63 < L_{eq} \leqslant 73$ dB(A)
Zone III : $L_{eq} \leqslant 63$ dB(A)

The insulation requirements are defined so that the indoor equivalent levels are between 30 and 40 dB(A).

3.3.5 - Collective Equipment Noise Insulation

The insulation against the noise of collective equipment is evaluated in terms of the A-weighted sound-pressure level in the center of a main room while the equipment is running. The maximum values of this A-weighted sound pressure level according to the laws and standards of European countries are given in table 3.8.

Table 3.8 - Maximum A-weighted Sound-Pressure-Levels in Dwelling due to Collective Equipment

B	$D_{(a)}$	$DK_{(b)}$	$F_{(c)}$	GB	$NL_{(d)}$	$Average_{(e)}$
-	30 to 40	30	30,35 (25)	-	30 to 40	-

(a) The German standard calls for two maximum values according to the time of the day : 40 dB(A) from 7 a.m to 10 p.m and 30 dB(A) from 10 p.m. to 7 a.m.

(b) The 30 dB(A) level in habitable rooms does not include the noise due to the switching on and off of compressors etc . Other limits are mandatory :

1) 35 dB(A) in a kitchen
2) 25 dB(A) for central heating noise
3) 35 dB(A) for noise radiated from common laundry and ironing facilities during day-time (7 a.m to 8 p.m)
4) 40 dB(A) for kitchen ventilation systems if the air volume removed is larger than the required minimum
5) The ventilation heating and garbage disposal systems must be constructed in such a way that the sound-pressure-levels, measured directly in front of the windows of residences and in the living spaces attached to those buildings including balconies, terraces, patios etc ... does not exceed 35 dB(A).

(c) The 35 dB (A) level quoted in the French legislation, is the maximum level in kitchens. It can be raised to 38 dB(A) for a mechanical air-moving device at the lowest air volume flow.

(d) The following maximum values are given in the standard NEN 1070 :

30 to 35 dB(A) in bedrooms

40 dB(A) in the other rooms

These values correspond to unfurnished rooms. If the measurements are performed in furnished rooms, the maximum values have to be reduced by 5 dB(A).

(e) No average can be computed here since the respective national methods and conditions differ.

3.3.6 - Insulation against Individual Equipment Noise

For individual equipment used in housing, the maximum A-weighted sound pressure levels permitted in the surrounding flats are given in table 3.9.

Table 3.9 - Maximum Permitted Sound Pressure Levels for Individual Equipment Noise in Surrounding Flats [dB(A)]

B	$D_{(a)}$	$DK_{(b)}$	$F_{(c)}$	GB	NL	Average (d)
-	30 to 40	-	35 (32)	-	30 to 40	-

(a) 40 dB(A) during day-time (7 a.m to 10 p.m)

(b) Equipment such as refrigerator and freezer must be built in such a way that the maximum A-weighted sound pressure levels, measured in living spaces of the same dwelling, do not exceed 30 dB(A)

(c) 38 dB(A) in kitchens

(d) No average can be computed because of the diversity of levels and time periods.

3.3.7 - Insulation against Airborne Noise within a Dwelling

Belgium has set requirements for the acoustical insulation between rooms of the same dwelling. These requirements, expressed by the airborne noise insulation quality index I_a in dB, are reproduced in table 3.10. The Dutch standard NEN 1070 also sets limits within a dwelling : the value of the insulation index I_{lu} is - 15 .

Table 3.10 - Airborne Sound Insulation Quality Index I_a Required in Belgium within Dwellings

	Bed-room	Living-room Dining-room	Kitchen	Play-room	Bathroom Toilet
Bathroom Toilet	43 (a)	51	34	34	34
Play-room	51	51	34		
Kitchen	51	43 (b)			
Living-room Dining-room	51				
Bed-room	43				

(a) does not apply to a bathroom opening from a bedroom
(b) does not apply to a dining-room or a living-room where meals are served

In order to simplify our evaluation of the acoustical comfort within a dwelling, the following terminology will be used :

1) "Noisy" rooms : kitchen, bathroom, play-room and toilet, living-room
2) "Sensitive" rooms : bedrooms

In the forthcoming classification of acoustical comfort in housing, a single value of the airborne noise insulation index I_a has been specified to limit the transmission between "noisy" rooms and "sensitive" rooms or between "sensitive" rooms. Though a more complicated system could be recommended, it does not appear necessary or economical in a single class system.

The value chosen is 42 dB as a reasonable compromise between acoustical and economical constraints. The 52 dB value chosen for the insulation within the dwelling would provide an exaggerated performance and would result in expensive acoustical control.

3.4 - Classes of Acoustical Comfort

3.4.1 - Recommended "Legal" Class

The classes which have been selected to define the acoustical comfort in housing are built around a recommended "legal" class which should be and could be implemented in the various European countries.

This class will be used as the median between the other categories.

Chapter 3.3. has shown that there are some differences between the various national requirements which set different values of the airborne noise insulation (I_a) and the impact noise insulation (I_i). These differences do not exceed a few dB but require that the various national criteria be separated. The recommended "legal" class(number 3) has been chosen to match a combination of reasonably severe requirements in effect or in preparation within the Community. This practice automatically places all the other existing European rules in a lower class; then, legal minima should be raised in most countries, since new laws are being prepared, thus letting class 3 represent the minimum European class of acoustical comfort.

3.4.2- The Five Classes of Acoustical Comfort

The recommended "legal" class is used as the hinge between the two classes of higher acoustical comfort and the two classes of lower acoustical comfort.

For a better than legal comfort :

Classe 2 : expresses improved acoustical conditions with respect to class 3. It also sets the minimum requirements for dwellings in quiet residential areas, rural areas and for hospitals and resthomes.

Class 1 : which is the most stringent class, sets superior criteria for dwellings in quiet areas.It can also be used to obtain an excellent acoustical comfort in dwellings where some particularly noisy activities are to take place, such as playing an instrument or using power-tools.

For a lower than legal comfort :

Class 4 : immediately under the recommended class 3, defines either the comfort obtained with most of the existing rules, which are inferior to those of class 3, or acoustic quality of some dwellings built before any rule existed.

Class 5 : will be used for all the dwellings which cannot be placed in one of the other classes.

The five classes which have been described cover the full range of acoustical comfort in housing.
Table 3.11 summarizes the roles of the various classes.

Table 3.11 - The five classes of acoustical comfort: definition

Class Number	Increasing Comfort ↑	Type of Acoustical Comfort.
1		Superior comfort in a quiet zone Minimum comfort in some cases.
2		Superior comfort in a normal zone Normal comfort in a quiet zone.
3		Recommended minimum comfort in a normal zone.
4		Comfort for some national rules Comfort of some "pre-rule" housing .
5		Mediocre acoustical quality.

3.4.3 - Detailed definition of the "Recommended legal class"

When comparing the national rules of acoustical comfort, one cannot escape the fact that there exist different standards in the various nations of the European Community. The rules that are in use in the Federal Republic of Germany are more severe than the others, but are reasonable constraints which will insure an excellent acoustical quality under normal conditions. Since the rules which are in effect in some other countries set a lower goal, but should be revised everywhere to define a comfort similar to that required in Germany .The Belgian and German standards combined with a forthcoming recommendation on impact noise, have been selected as a basis for the "recommended legal class". The parameters and criteria used are defined in tables 3.1 to 3.10 and summarized in table 3.12.

Table 3.12 - Class 3 : Recommended Legal Minima

1) Insulation between two dwellings	Against Airborne Noise Against Impact Noise	I_a = 52 dB I_i = 65 dB
2) Insulation between a dwelling and the common circulation spaces	Against Airborne Noise Against Impact Noise	I_a = 52 dB[(a)] I_i = 65 dB
3) Insulation between a dwelling and industrial or commercial premises or a workshop	Against Airborne Noise Against Impact Noise	I_a= 62 dB I_i= 45 dB
4) Insulation against outdoor noise	Maximum indoor level [(c)] L_{eq} : Daytime Nighttime	 35-40 dB(A) 30-35 dB(A)
	Peak Noise level should not exceed following values: Daytime Nighttime	45-50 dB(A) 40-45 dB(A)
5) Insulation against common equipment noise	Maximum sound pressure	L_p = 30 dB(A) [(b)]

6)	Insulation against individual equipment noise	Maximum sound pressure level	$L_p = 35$ dB(A)
7)	Insulation against airborne noise within a dwelling	Between a sensitive room and a noisy room or between sensitive rooms.	$I_a = 42$ dB

(a) Between common spaces and a living-room or bed-rooms. Between common spaces and an entrance hall, the requirement can be lowered by 10 dB.

(b) The requirement can be raised to 40 dB(A) if the collective equipment runs only between 7 a.m and 10 p.m.

(c) If the noise is impulsive or contains audible tone components or both, add 5 dB to measured L_{eq}.

3.4.4 - Steps between Classes

From the reference class 3, the criteria of acoustical comfort can be selected for the other four classes by increasing or decreasing the criteria of class 3, thereby defining the steps between classes.

3.4.4.1 - Steps between class 3 and class 2

For airborne noise insulation, the classes 2 and 3 are separated by 3 dB : this value has been chosen to fulfil the following conditions :

a) The step between classes must be large enough so that the difference in noise levels between classes, all other conditions remaining identical, is clearly perceptible.

b) The step must not be so wide that the cost increment between classes is too large.

c) The step must correspond to reasonable changes of the physical characteristics of the construction.

The motivation behind the 3 dB choice is based on an empirical formula [26] which describes the practical implications of the mass law [3] for a single partition made of heavy materials such as concrete, bricks, plaster or glass. It gives the airborne noise insulation margin LSM or M_a (modified-ISO) "in situ" :

$$LSM = -14 + 25 \log \frac{m}{100}$$

with

$$I_a = LSM + 52$$

where m is the surface mass of the material in kg/m^2. A 3 dB improvement of the acoustical performance corresponds to an increase of 30% of the mass.

For instance, for two adjacent dwellings, a 16 cm concrete skin (2500 kg/m^3) would provide an airborne sound insulation index I_a of 53 dB, that would fulfill one of the requirements of class 3. To reach the constraints of the better class 2, it would be sufficient to increase the thickness of concrete to 21 cm : an I_a index of 56 dB would result.

If the step between classes 2 and 3 was larger that 3 dB, the thickness of the outside walls would have to be increased beyond the usual construction standard (a 4 dB step would require a 45% increase, 5 dB requires 58% etc.).

One exception to the 3 dB step rule has been allowed for the airborne noise insulation between a dwelling and commercial, industrial or workshop premises for which the requirements of class 3 are already very severe and could not be increased through simple techniques.

The step for impact noise insulation has been set at 10 dB for the following reasons. A 16 cm concrete floor, a common type of construction, provides an impact sound insulation index I_i of 75 dB, a performance which would not fulfil the requirements of class 3. Doubling the floor thickness would lead to an index I_i of 66 dB which would not be sufficient for class 3 and moreover would be uneconomical. Therefore, for class 3 a more appropriate solution would be to combine a 16 cm concrete floor with another impact noise reduction device such as a resilient floor or a floating slab. These techniques can provide 10 or 20 dB additional insulation if the construction of the floor is without flaws.

Table 3.13 shows some examples of the improvements expected with various floors.

Table 3.13 - Improvements of the Impact Sound Insulation Margin for Various Floor Coverings or Floating Slabs (27)

Floor Coverings	
Linoleum or PVC without underlay	3 to 7 dB
Linoleum on 2 mm cork	15 dB
Linoleum on 3 mm felt	15 to 19 dB
Short-pile carpet	18 to 22 dB
Long-pile carpet	25 to 35 dB
Floating Concrete Screeds	
On corrugated cardboard	18 dB
on hard sponge-rubber underlay	approx. 18 dB
on soft sponge-rubber underlay	approx. 25 dB
on mineral wool	27 to 33 dB

For insulation against outdoor noise as well as common or individual equipment noise, the step is 5 dB a value which is representative of a clearly perceptible improvement of the acoustical comfort. A larger value, 10 dB for instance, would require too important a technological jump from the lower class.

3.4.4.2 - Steps between Classes 2 and 1

In class 1, the airborne sound insulation has been set 10 dB above class 3 or 7 dB above class 2.

We have shown that a 3 dB jump was most convenient between class 3 and class 2, for technical and economical reasons, if one is limited to the use of simple partitions. For larger steps, one is required to build double walls with a dilation joint between the two layers or to add a light partition, completely independent, in front of a heavy wall.

For instance, the types of construction shown in figures 3.1 and 3.2 could be used for class 1.

According to the value of a or b defining the spacing between layers the index I_a can be increased by 10 dB or even more (for instance for a = 2 cm and b = 10 cm).

For the airborne sound insulation between a dwelling and industrial, commercial or workshop premises, the requirements of classes 2 and 3 (see 3.4.4.1) have been raised by 5 dB for class 1, to take into account that this class represents an excellent comfort (i.e. a low background noise level).

As far as the impact sound insulation index I_i is concerned, the step between classes 2 and 1 has been set at 10 dB for reasons which have been already developped in the preceeding section. For class 1, to reach an improved level of acoustical comfort, the noise radiated by impacts should not be heard. According to a scale [28] of subjective judgments of the impact noise insulation index I_i, footstep noises become inaudible for values of I_i inferior to 48 dB, while furniture movements are still weakly perceptible. The scale is given in table 3.14. Between a dwelling and commercial, industrial or workshop premises, the step of I_i has been increased to 5 dB for the same reason as for the airborne insulation.

Table 3.14 - Subjective Judgments of Impact Noise Ratings (after 28)

Impact Sound Margin E_T (dB)	Impact Sound Insulation Index I_i (dB)	Subjective Judgment	
		Footsteps	Furniture movement
- 20	88	clearly audible	very noisy
- 10	78	clearly audible	clearly audible
0	68	audible	clearly audible
+ 10	58	weakly audible	audible
+ 20	48	inaudible	weakly audible

Fig. 3.1 - Example of Construction Type for Class 1

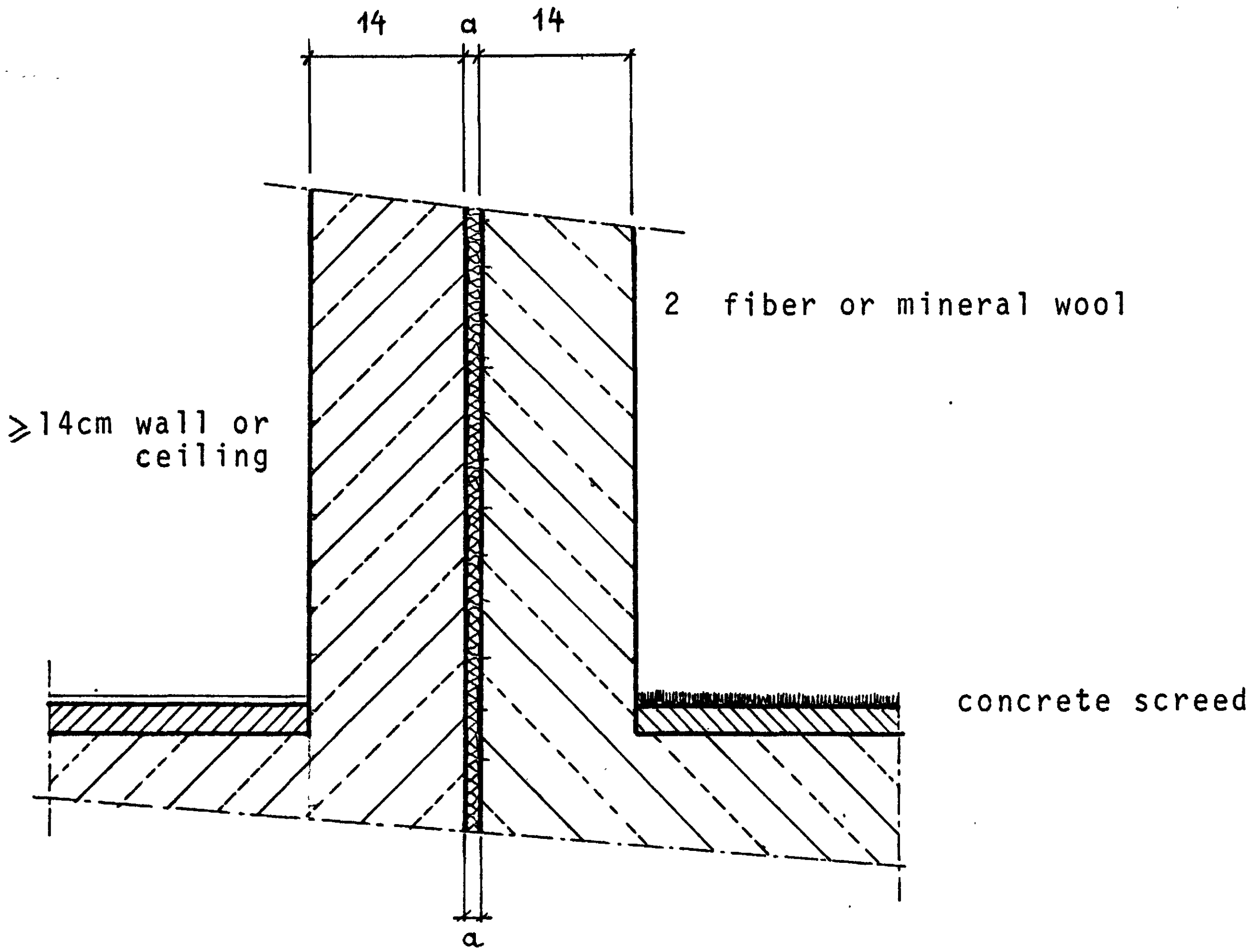
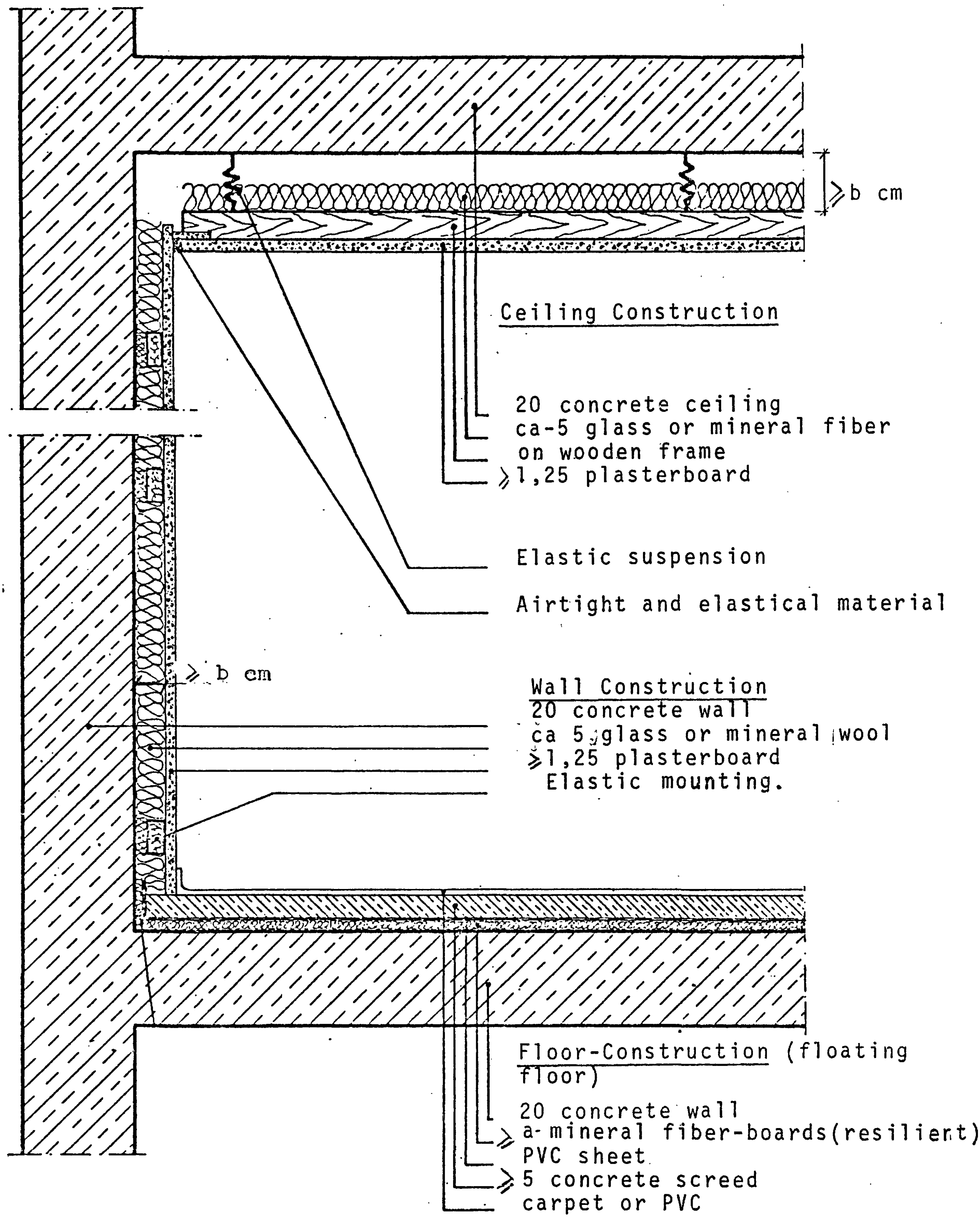


Fig.3.2 - Example of Construction Type for Class 1

(dimensions in cm)



By choosing I_i= 45 dB, one is reasonably sure that most impact noises will not be heard.

For the indoor maximum sound-pressure levels due to outdoor noises and individual equipment, the step has been set to 5 dB for the reasons explained earlier in section 3.4.4.1. For the maximum levels due to common equipment, the same value as in class 2 has been maintained since a lower one is in practice very difficult to reach.

3.4.4.3 - Steps between Class 3 and Class 4

The minimum value of the airborne sound index I_a is set to 47 dB in class 4, corresponding to a decrease of 5 dB from the insulation index of class 3. To achieve I_a = 47 dB, one must use 11.5 cm of plain bricks, 10 cm of concrete or 20 cm of light concrete (ρ = 1200 kg/m^3), if the flanking walls and floors can be assumed to provide a higher index I_a. These types of constructions have been common in the past, before any legislation had been passed.

Exceptionally for airborne noise, the 5 dB step has not been applied for the insulation between rooms of a same dwelling since noise transmission limits for sources within an apartment or house should appear only in a relatively elaborate category, namely class 3.

To obtain the maximum permissible levels due to outdoor noises in other classes 5 dB steps have also been chosen.

The impact sound insulation index I_i has been raised by 5 dB. Table 3.14 has shown that the values I_i corresponding to an audible and strongly audible impact noise are respectively 68 and 78 dB. The 70 dB index has been chosen as the borderline between the two.

For the impact noise insulation between a dwelling and industrial, commercial or workshop premises, a maximum value of 70 dB is allowed for I_i.

3.4.4.4 - Steps between Class 4 and Class 5

Class 5 obviously contains all the constructions which offer only a mediocre acoustical comfort : maximum values are set for the airborne noise insulation index and minimum values are given for the impact sound insulation index.

3.4.5 - Summary of the Classes of Acoustical Comfort

The information contained in the previous sections is gathered in table 3.15.

Each class is well-defined and a type of construction can belong to a given class only if all the required values are met, namely minimum values for the airborne sound insulation index and maximum values for the impact sound insulation index and equivalent sound pressure level. When a single requirement is not met, the dwellings under scrutiny must be dropped to the lower class. However, if the requirements of the upper class are met within one or several categories, the symbol "+" will follow the class number (for example : class 4 +).

The parameters used are defined in chapter 2 and the measurement and control methods in chapter 5.

The classes of acoustical comfort described here can be adapted to any new measurement or comfort parameter, since only the column corresponding to the new or modified variable and criterion has to be changed. Similarly, new parameters may be added to the system if required using additional columns. It is expected, for instance, that recent contributions in the areas of vibrations and impact noise assessment could be used to modify or expand the present system.

Table 3.15 - Classes of Acoustical Comfort *

CLASSES OF ACOUSTICAL COMFORT *	INSULATION BETWEEN TWO DWELLINGS		INSULATION BETWEEN A DWELLING AND the COMMON CIRCULATION		INSULATION BETWEEN A DWELLING AND COMMERCIAL INDUSTRIAL OR WORK PREMISES		INSULATION AGAINST OUTDOOR NOISE (3)		INSULATION AGAINST NOISE FROM COMMON EQUIPMENT (8)	INSULATION AGAINST NOISE FROM INDIVIDUAL EQUIPMENT (4)(8)	INSULATION AGAINST AIRBORNE NOISE WITHIN A DWELLING (5-6-7)
	Against Airborne Noise I_a(dB)	Against Impact Noise I_i(dB)	Against Airborne Noise (2) I_a(dB)	Against Impact Noise I_i(dB)	Against Airborne Noise I_a(dB)	Against Impact Noise I_i(dB)	$L_{eq}^{(8)}$ dB(A)	Maximum Value of the Measured SPL dB(A)	dB(A)	dB(A)	I_a(dB)
1	62	45	62	45	67	40	25	35	<25	<25	45
2	55	55	55	55	62	45	30	40	25	30	45
3	52 (55)(1)	65	52	65	62	45	35	45	30	35	42
4	47	70	47	70	52	70	(40)	(50)	35	40	-
5	<47	>70	<47	>70	<52	>70	-	-	>35	>40	-

* A type of building can belong to a given class only if all the required values are met. When a single requirement is not met, the building under scrutiny shall be dropped to the lower class.

However, if the requirements of the upper class are met within one or several categories, the symbol " + " will follow the class number.

Notes:
1) Values in brackets correspond to individual houses, semi-detached or in a row.
2) The values given in classes 2 and 3 have to be increased by 3 dB for walls and floors separating a dwelling from a common garage or access ramp. These values can be lowered by 10 dB for the insulation between an entrance hall and common circulation spaces.
3) The maximum levels apply to bed-rooms during night-time (20.00 to 07.00); for day-time (07.00 to 20.00) the levels can be raised by 5 dB.
4) The criteria to be applied to industrial, commercial or workshop equipment are the same as for buildings.
5) Noisy rooms: toilet, kitchen, bathroom, play-room, living-room.
6) Sensitive rooms: bed-rooms.
7) Between sensitive rooms or between noisy rooms and sensitive rooms.
8) If the noise is impulsive or contains audible tone components or both, add 5 dB to measured level.

4 - CLASSES OF ACOUSTICAL COMFORT ACCORDING TO AREA AND TYPE OF HOUSING

4.1 - Introduction

The classes of acoustical comfort that have been defined in chapter 3 cannot be used as such without taking into consideration the type of area in which the dwellings are located. For individual houses or collective housing, acoustical comfort depends, not only on the absolute indoor sound pressure levels but also on the ambient level of the urban, residential, rural or industrial area that surrounds the building.

4.2 - Effect of Outdoor Ambient Noise

In rural areas,the night-time equivalent level can be as low as 35 dB(A) and the background level can sink to 25 or 30 dB(A). On the contrary, in urban centers, nightime equivalent and background levels have been typically measured, outside of a fifth floor on a major artery at 60 and 54 dB(A) respectively.

The effect of a background noise on acoustical comfort is twofold. On the one hand, there is a negative effect due to the loud background level; on the other hand, there is a positive impact since this noise overshadows the noises transmitted from the neighbouring dwellings through the walls, making them inaudible.

In class 3, the recommended legal class, the insulation that is required against outside noise sources limits the effect of the outdoor background level. The indoor equivalent levels cannot exceed :

during night-time L_{eq} = 35 dB(A)

during day-time L_{eq} = 40 dB(A)

Acoustical comfort does not depend only on the limits which are imposed on the intrusion of noise from nearby dwellings, but also on the indoor background noise which results from the noise outside the building. Consider, for example, (fig.4.1) two identical dwellings, the first being located in an urban area, the second in a rural area. The acoustical requirements of class 3 have been met by both constructions and the indoor background level is 30 to 35 dB(A) in the urban area and less than 30 dB(A) in the rural area. Assume that a sound pressure level of 86 dB(A) corresponding to 80 dB in each octave band from 125 to 4000 Hz, is emitted in a dwelling. If the partition provides an insulation of 52 dB, the resulting level in the next flat will be about 34dB(A) in both cases. In the urban area, this level will be overshadowed by the background noise level while, in the rural area, it will remain 4 dB(A) above and will be audible and annoying. Therefore, the requirements for impact and airborne noise insulation will have to be more stringent in "quiet" areas so that the noise transmitted to the neighbouring dwellings can be masked.

However, it would be erroneous to conclude hastily that the noisier the area the weaker the insulation since class 3 sets the same maximum level for the immission of outdoor noise.

If the acoustical requirements on the rural area dwelling are raised from class 3 to class 2, the transmitted noise level will decrease to :

$$L_2 = 86 - 55 = 31 \text{ dB(A)}$$

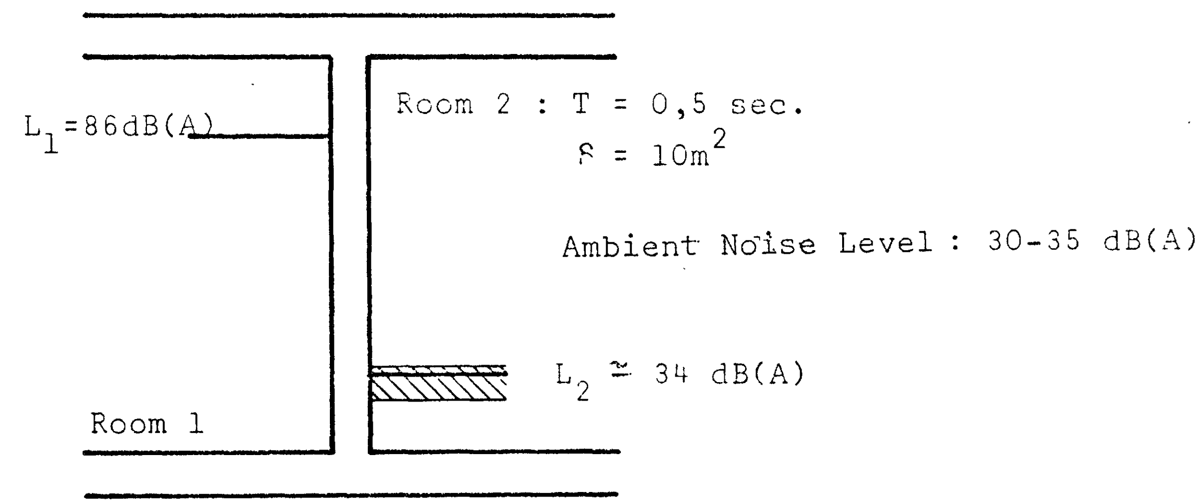
and will be masked by the background. The acoustical comfort will be similar to that in the urban area dwelling corresponding to class 3. Similarly, class 1 in a rural area will correspond to class 2 in an urban area. The effect of the area on the acoustical comfort of dwellings is summarized in table 4.1 :

Table 4.1 - Type of Area and Acoustical Comfort

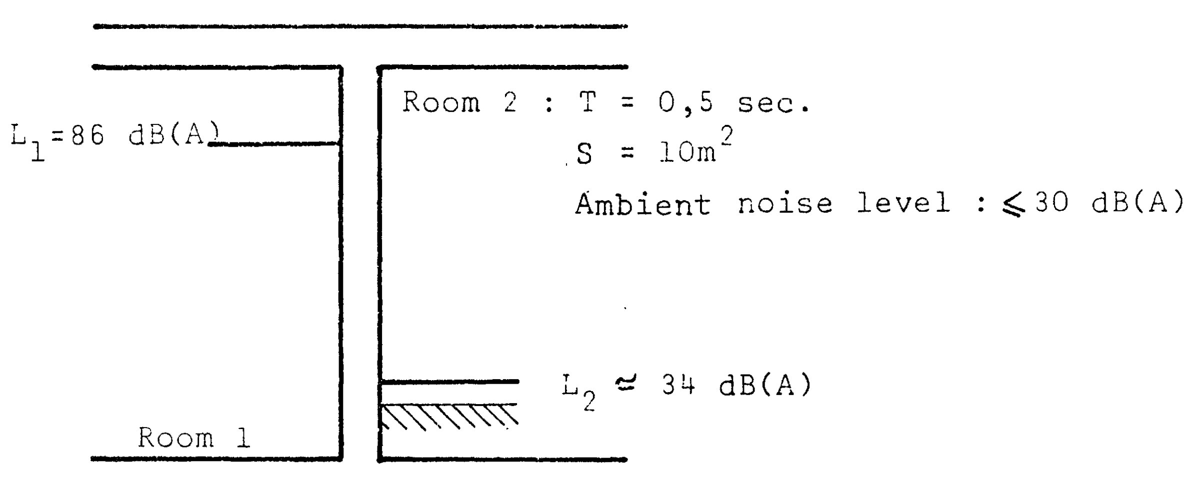
Type of Area	Classe N° For the same Comfort
Quiet Area (purely residential, rural, hospitals, resthomes) [Indoor Background Level 30 dB(A)]	N - 1
Other Areas (Urban, suburban etc ...) [Indoor Background level 30-35dB(A)]	N

Fig. 4.1 - Effect of Background Noise on Acoustical Comfort

Urban area



Rural Area



4.3 - Effect of the Type of Housing

The influence of the housing characteristics, collective apartment houses, individual homes, semi-detached or row houses, housing mixed with industrial , commercial or workshop premises is similar to that of the area since it affects the background noise. For identical building quality requirements, an apartment surrounded by other dwellings will be submitted to a higher background level than a semi-detached home or even a house in a row. This will have to enter into the criteria at least for airborne noise transmission. Therefore, in class 3, the airborne noise insulation index is required to be 3 dB higher for flats than for individual semi-detached or row houses. For impact noise, the number of annoying sources is approximately the same for both types of dwellings since lateral and lower neighbours have less influence than the upper neighbour.

In summary, the modulation of the acoustical requirements in terms of the type of housing has an effect only on airborne noise insulation; this has been included in table 3.15.

For dwellings located near premises which are not to be used for housing, the requirements have also been included in the class system. The insulation requirements have been increased (by 10 dB for class 2 and 15 dB for class 1) to avoid any interference of the noisy activities of industrial, commercial and workshop premises. By adjusting appropriately the acoustical insulation of the walls to the sound power levels of noisy equipment, it is possible not to exceed the noise levels due to collective equipment.

5 - MEASUREMENT TECHNIQUES AND PROCEDURES

5.1 - Introduction

The measurement techniques used in housing evolve constantly, in general towards simplification. The currently available standardized procedures, which can be applied to the measurement or the assessment of acoustical comfort in housing, as described in the preceeding chapters are reviewed here. The parameters are those described in chapter 2.

- Airborne Noise Insulation : $D_{n,T}$, Normalized Sound Level Difference in dB

- Impact Noise Insulation : $L_{n,T}$, Normalized Impact Sound Pressure Level in dB

- Outdoor Noise Insulation : L_{eq}, Equivalent Sound Pressure Level in dB(A)

- Collective and Individual Equipment : L_A, A-weighted Sound Pressure Level in dB(A)

The present chapter is needed to classify the definitions used in the class system. In the future, as more international standards become available, the procedures described below could be altered accordingly. Meanwhile, they have been derived from the following standards and recommendations :

The measurement procedures described below have been derived from the following standards and recommendations :

DIN 45641 : "Averaging of time varying Sound Levels, Rating Level" (February 1975)

DIN 52210 : "Tests in Building Acoustics, Airborne and Impact Sound Insulation" :
Part 1 : "Measuring Method" (July 1975)
Part 5 : "Field Measurement of Airborne Insulation of Windows and Façades" (December 1975)

DIN 52212 : " Testing of Architectural Acoustics. Measurements of Sound Absorption in a Reverberation Room" (January 1961)

DIN 52219 : " Tests in Building Acoustics, Field Measurements of Plumbing Noise " (March 1972)

VDI 2058 : " Beurteilung von Arbeitslärm in der Nachbarschaft". (Estimation of working noise in the neighbourhood) (August 1971)

NF S 31-002 : "Mesure en laboratoire et sur place de la Transmission de Sons aériens et des Bruits de chocs dans les Constructions " (Novembre 1956)

NF S 31-010 : " Acoustics Measurements of the Noise in inhabited Areas with a View to evaluate the Discomfort to the Population" (September 1974)

Circulaire N° 72-110 du 29 juin 1972 relative au Label du Confort Acoustique - B.O. du Ministère de l'Equipement et du Logement et du Ministère des Transports.

ISO/R 140-1960(E) : " Field and Laboratory Measurements of Airborne and Impact Sound Transmission" (January 1960) (to be revised)

ISO/R 717-1968 (E) : " Rating of Sound Insulation for Dwellings" (May 1968)

ISO/R 1996-1971(E) : " Assessment of Noise with respect to Community Response"(May 1971) (to be revised)

IEC-179 : " Specification for Precision Sound Level Meters"

IEC-225 : " Specification for Octave, Half-Octave and Third-Octave Band pass filters intended for the Analysis of Sounds and Vibrations"

IEC-Draft SC 29c WG 11 : "Integrating Sound Level Meters"

5.2 - Airborne Noise Isolation

5.2.1 - Measurement Parameters

The parameters to be measured to determine the normalized sound pressure level difference :

$$D_{n,T} = L_1 - L_2 + 10 \log \frac{T}{0,5}$$

are :

L_1 : the sound pressure level in the emitting room in dB (re. 2×10^{-5} Pa)

L_2 : the sound pressure level in the receiving room in dB (re. 2×10^{-5} Pa)

T : the reverberation time in the receiving room in seconds

5.2.2 - Testing Apparatus

5.2.2.1 - Emission

- Noise source :
  - If a stationary noise is used, its level should not vary by more than 6 dB in each octave band, if unfiltered. It can however be filtered in octave or third-octave bands.
  - If a warble tone is used, the frequency deviation should be at least $\pm$ 10% of the main frequency, with a modulation of 6 Hz; at 500 Hz, however, a frequency deviation of 50 Hz is sufficient.
  - For reverberation time measurements, impulse signals should be avoided(1)

(1) In standard rooms, measurements performed with a pistol or with a white noise source cannot be compared.

- Emitting transducers : - Loudspeakers should be assembled so that an isotropic sound field is generated. To obtain a quasi-omnidirectional source, one can assemble twelve loudspeakers in the shape of a dodecahedron.

- Sound Power level : - The sound power of the source must be such that the resulting sound pressure level in the receiving room is 10 dB above the background noise, at least.

5.2.2.2 - Measurement Apparatus

- Noise Level Measurement :
  - Precision sound level meter in compliance with IEC-179 with an omnidirectional microphone
  - Octave or third-octave band filter in compliance with IEC-225

- Reverberation Time Measurement :
  - Recording device such as a noise level recorder, an oscillograph with logarithmic amplifier or any other system that is useable for the measurement of sound decay in a room.

- Calibration of Instruments :
  - The precision sound level meter must be calibrated at the beginning and at the end of each series of measurement or when any event shed any doubt on the quality of the measurement.

- An electromechanical calibrator can be used in general if a check is performed with a pistonphone periodically or with an electrostatic actuator.

- Tests of Equipment :

  - The instrumentation should be tested regularly, at least every two years, by an approved testing agency.

5.2.3 - Measurement Procedure

5.2.3.1- Frequency Bands

For control measurements, the levels L_1 and L_2 and the reverberation time in the receiving room should be measured in the octave bands centered on 125, 250, 500, 1000 and 2000 Hz.

For a finer analysis, these quantities should be measured in the third-octave bands centered on 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500 and 3150 Hz.

5.2.3.2 - Loudspeaker positions

The loudspeaker(s) should be placed not closer than 2 meters from a separating wall or ceiling. For vertical airborne noise insulation measurements, the loudspeaker(s) should be placed in the lower room. The loudspeaker(s) should never be placed at points of symmetry of the room.

5.2.3.3. - Microphone position

<u>Sound Pressure Levels</u> :

For normal rooms (V from 30 to 100 m^3), measurements should be performed at three positions (1).

(1) a minimum of six positions would be required to insure reliable results; practical considerations indicate that three may do in most cases.

For each position, a different microphone height should be chosen. The microphone should never be closer to the walls or ceiling than 1m and to the loudspeaker than 0,5m. A moving microphone system may be used.

Reverberation Time : At least two microphone positions are required.

5.2.3.4 - Averaging Sound Pressure Levels

If the measured differences are less than 10 dB, a simple arithmetic average can be performed :

$$\bar{L} = \frac{1}{n} \cdot (L_1 + L_2 + \cdots + L_n)$$

If the differences are larger than 10 dB, an energy average is needed :

$$\bar{L} = 10 \log \frac{1}{n} \sum_i 10^{0,1 L_i}$$

5.2.4 - Presentation of Results

The values of the normalized level differences $D_{n,T}$ should be shown for all octave-bands or third-octave bands with a reference reverberation time of 0,5 sec.

The value of the airborne sound insulation index I_a should be computed and reported. The characteristics of the rooms, volume, size, furniture, should be given. The dimensions of the separating wall or ceiling should also be given so that, if necessary, the airborne transmission loss R' can be found :

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

where S is the area of the separating wall or ceiling in m^2.

5.3 - Impact Noise Isolation

5.3.1 - Measurement Parameters

$$L_{n,T} = L + 10 \log \frac{T}{0,5}$$

one has to measure :

- the sound pressure level L, in dB re. 2×10^{-5} P_a in the receiving room
- the reverberation time T, in seconds, in the receiving room

5.3.2 - Testing Apparatus

5.3.2.1 - Noise Source

The impact noise should be generated by the normalized tapping machine defined by ISO R 140 [(24)]. It requires that the hammers fall freely and that no double strikes occur.

5.3.2.2 - Measurement Apparatus

The devices described in section 5.2.2.2 should be used.

5.3.2.3 - Test of Equipment

The standardized tapping machine and the precision sound level meter should be checked regularly and tested by an approved testing agency at least every two years.

5.3.3 - Measurement Procedure

5.3.3.1 - Frequency Bands

The sound pressure level L should be measured in the octave bands centered on 125, 250, 500,1000 and 2000 Hz.

For finer analyses, third-octave bands should be used : 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500 and 3150 Hz.

5.3.3.2 - Location of the Standardized Tapping Machine

The tapping machine should be placed at, at least, three different positions. If the ceiling is anisotropic, more positions are needed (ribbed concrete or wood-joists). The tapping machine should always be at least 1 meter away from the walls.

5.3.3.3. - Microphone positions

The criteria for positionning the microphone are those of section 5.2.3.3.

5.3.3.4 - Averaging Sound Pressure Levels

The procedure is that of section 5.2.3.4.

5.3.4 - Presentation of Results

The values of the normalized level differences $D_{n,T}$ should be shown for all octave bands or third-octave bands, with a reference reverberation time of 0,5 sec. The values of the impact sound insulation index I_i should be computed and reported. If the measurements are performed in third-octave bands, the octave-band values should be computed, to obtain I_a , since the reference spectrum is defined in octave bands.

5.4 - Isolation against External Noise

5.4.1 - Measurement parameter

The measurement parameter used to set the criteria relative to insulation against external noise is the equivalent sound pressure level defined from the A-weighted sound pressure level L_A over a time T

$$L_{eq} = 10 \log \left[\frac{1}{T} \int_0^T 10^{0,1\, L_A(t)} \, dt \right] \text{ dB(A)}$$

If L_A is time independent, then $L_{eq} = L_A$

5.4.2 - Measurement Instrumentation

5.4.2.1 - Sound Pressure Level

The A-weighted sound pressure level L_A will be measured with a precision sound-level meter, as defined in IEC-179 , on the "fast" setting.

5.4.2.2.- Equivalent Level

The equivalent level can be determined with an integrating sound-level meter according to IEC-Draft SC 29c WG 11 or with any device permitting the statistical analysis of noise signals. For discrete sampling

$$L_{eq} = 10 \log \left[\frac{1}{N} \sum_{i=1}^{n} N_i \, 10^{0,1\, L_i} \right] \text{ dB(A)}$$

where :

L_{eq} is the equivalent sound pressure level in dB(A)

L_i is the sound level in dB(A) corresponding to the class-midpoint of the class i

N_i the number of times the sound pressure level assumes the value L_i

N the total number of samples $N = \sum_{i=1}^{n} N_i$

n the number of sound pressure level classes

5.4.2.3 - Test of Equipment

see section 5.3.2.3

5.4.3 - Measurement Procedure

5.4.3.1 - Microphone position and effect of room characteristics

The microphone should be placed near the center of the room, at a height above the floor , of about 1.2m. The measurements should be performed with closed doors and windows. If the impinging noise contains pure tones, precautions should be taken by averaging measurements at several points, to avoid standing waves. If the measurement is performed in an unfurnished room, the equivalent level should be corrected by substracting :

$$\Delta L_{eq} = 10 \log \frac{T\ empty}{T\ real}$$

where T_{real} is the measured reverberation time in second in the furnished room, which, if unknown, will be assumed to be 0,5 sec.

5.4.3.2 - Time and Duration of the Measurement

The measurements will be performed over two periods : 7 a.m to 10 p.m and 10 p.m to 7 a.m, on a working day.

If no highly variable noise source is present, the measurement can last about 15 minutes.If the noise level is constant,a single reading of the A-weighted sound pressure level is sufficient.

5.4.3.3.- Influence of Extraneous and Background Noises

Extraneous noises are those which occur at the measurement location but are not relevant to the evaluation of the effect of the outdoor noise. They can be due, for instance, to common or collective equipment noise or to human activity. Background noise is, according to ISO/R-1996, "the mean minimum sound level at the relevant place and time in the absence of the noise which is alleged to be offending. It should be obtained by observing the pointer of the sound level meter and by reading the lowest level which is repeated several times (mean minimum). When statistical analysis of the sound level is used, the background noise level should be taken as that level which is exceeded for 95% of the observation time".

The extraneous and background noises should be separated from the impinging noise to be measured.

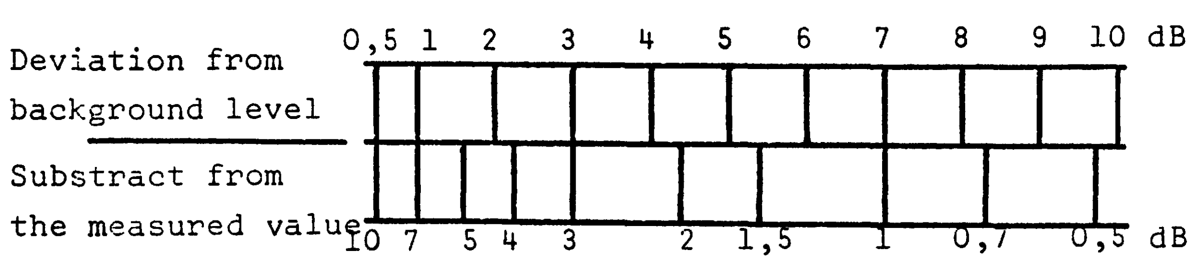
Corrections for extraneous noises

For strongly varying extraneous noises, the impinging noise levels should be measured only during those times when extraneous noises are absent. Sources of extraneous noise, such as heaters, neighbours, dogs, etc, should be eleminated during measurements. If it is not possible to control extraneous noise sources, a tape recording must be made from which unwanted noises could be eliminated.

Corrections for background noise

If unwanted background noise is less than 10 dB under the measured "immission" level, it may be necessary to correct the latter to obtain its real value. The use of the following table is then necessary

Fig.5.1 - Nomograph for the assessment of the effect of background noise(46)



5.4.4 - Notation of Results

The equivalent sound-pressure level should be presented as :

a) the equivalent level during daytime (07.00 to 10.00).

b) the hourly equivalent level during nighttime (10.00 to 07.00).

The actual duration and time of the measurements should be stated. Data on the outside walls and windows as well as on the nature of the outdoor noise sources should also be gathered so that the measured values can be properly judged.

5.5 - Isolation against Common and Individual Equipment

5.5.1 - Measurement Parameters

The quantity to be measured is the A-weighted sound-pressure level in the flat. Such equipment can consist of a heating plant, a lift, plumbing etc.

5.5.2 - Measuring Instrumentation

A **precision** sound level meter, complying with IEC -179 , should be used on the "fast" setting.

If the measurements are performed in an empty room, the results should be corrected by :

$$10 \log \frac{T\ real}{T\ empty}$$

where , T_{empty} is the measured reverberation time in seconds in the empty room.

- T_{real} is the reverberation time in the furnished room, which if unknown, will be assumed to be 0.5 sec.

For measurements on water supply systems, the following rules should be observed :

- the water pipes should be fully opened and closed several times. In the case of mixers, the two faucets should be activated separately.

- If hot water is produced by an individual heater, it should be active during the measurement.

- Measurements on toilet water supply devices must be performed during a complete cycle (as described for example in DIN 52219).

5.5.3 - Measurement Procedure

5.5.3.1 - Common Equipment

The A-weighted sound pressure level should be measured near the center of the living-room or of a main room, at a height of about 1,2m above the floor, while the equipment is operating under normal conditions.

In most cases, the noise emitted is discontinuous (lift, burner). The sound-pressure level should be obtained during the noisiest phase which is repetitive. If the room is connected to a mechanical ventilation system the measurement should be performed in the room which is closest to the equipment. If the vents are adjustable, they should be adjusted for maximum and minimum airflow : the least favourable level should be kept.

5.5.3.2 - Individual Equipment

As a rule, the systems to be tested should be prepared so that they function normally : in particular, the air enclosed within piping networks should be removed.

Corrections should be made for background noise (cf. 5.4.3.3)

6 - Tentative Evaluation of the Economic Impact of Acoustical Comfort.

6.1 - Introduction

To give their full significance to the classes of acoustical comfort described in the preceeding chapters, one must evaluate the cost increments as one moves up the scale of classes. This is not a trivial question : to answer it would require an in-depth study of all the technical means which may be required to go from one class to the next, of a complete range of buildings, from the smallest to the largest and the models would have to be evaluated for each of the national and regional economic structures, throughout the Common Market. Such a task would also require unreasonable funding.

The reader should therefore be warned that the following evaluation of the economic impact of the classes of acoustical comfort constitutes merely an example, with a limited validity, which should not be extrapolated.

Theoretically, a complete study of the financial effect of acoustical comfort would be feasible since it is possible to price all the techniques and materials which are called upon to achieve a given acoustical performance. By adding all the additional expenses for a whole building, one could reach a conclusion about the overall cost increment for that particular building. Such a study requires a detailed knowledge of the following points :

1) Secondary economic effects of the various techniques of improvement of acoustical comfort
   Examples : by increasing the mass of the partitions of a dwelling (i.e. walls and floors), the airborne noise insulation will improve. The cost increment will result not only from the higher price of the partitions but also from the increased cost of the foundations, which would have to be reinforced.

- to build a comfortable dwelling in a noisy urban area , of class 3, the windows will have to be of high acoustical quality. It may be required to use sealed windows and to design a forced ventilation system throughout the building or a costly, well insulated ventilation through the façade. The cost of such systems will have to be added to the cost of the windows.

2) **Discrimination between the construction elements which affect acoustical comfort.**

The total cost P of a building is the sum of the costs P_1 which vary according to acoustical quality and of the costs P_2 which are independent from it. If P_1 can be computed quite accurately, P_2, on the contrary, is hard to estimate. It includes :

- the price of the land,
- the cost of materials and equipments which do not contribute to acoustical comfort.

It varies from one country to another, one town to another and even from one neighbourhood to the next.

3) **Economic evaluation of all solutions to each acoustical problem**

4) **Relative cost of building in the countries** member **of the European Community.**

Since it was not possible to answer all those questions, the objective of the present study was limited to the determination of the order of magnitude of the cost of a single type of building, assumed to be built in the Paris area using the technology and materials available in France.[*] The detailed characteristics of the building are given in section 6.2. Once the basic construction has been defined, one can modify it to make it fulfil the contraints of each of the classes of acoustical comfort (section 6.3).

[*] Prices are in 1976 French Francs (F)

The price of the construction elements is computed for each step (section 6.4) and finally the increments per class can be evaluated for the completed buildings. The reference price P of a flat, of class 4, has been set at 2 300 F/m^2. Computing then P_1 for class 4 which includes the cost of all the elements that have an effect upon acoustical comfort, P_2 can be found. P_2 was assumed to remain constant for all the classes above 4. For class 5, a reference price P of 1 550 F/m^2 was chosen.

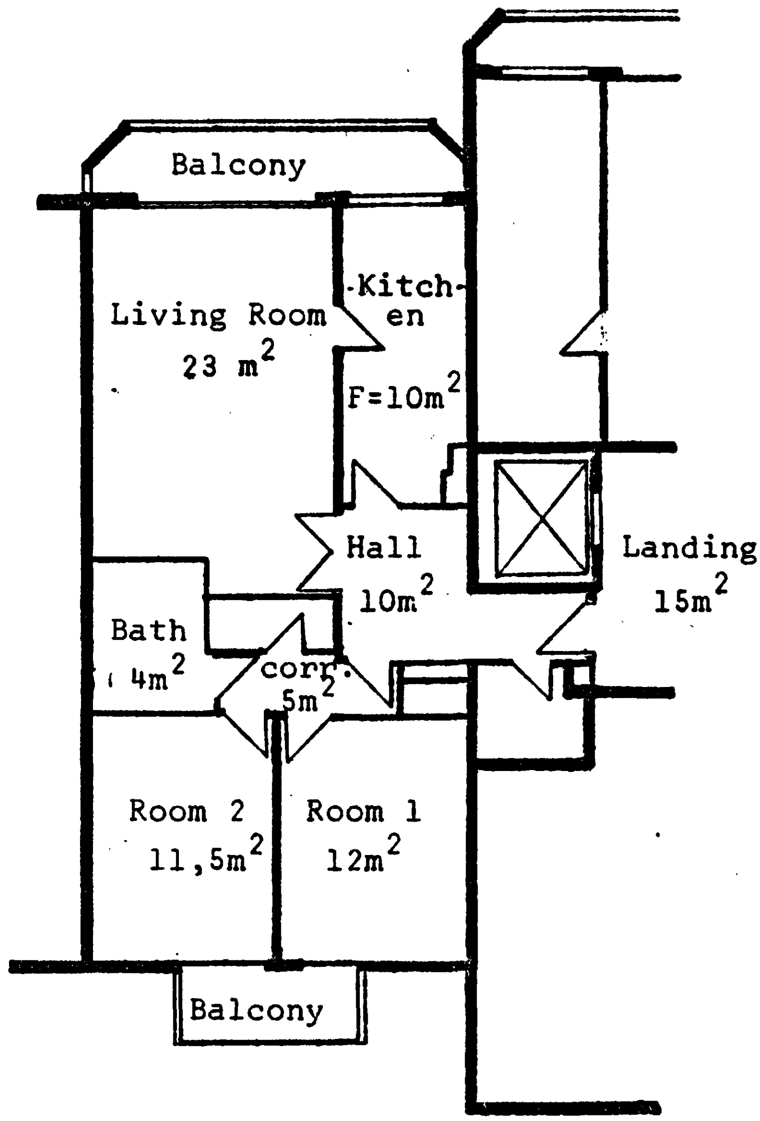
6.2 - Specifications of the Reference Dwelling

6.2.1 - General Features

- Location : urban area (outdoor L_{eq} is 70 dB(A) during daytime and 60 dB(A) during nightime).[47]
- Type : multiple dwelling
- Number of dwellings : 80 flats in two five-story buildings, four flats per floor
- Reference flat : three rooms, kitchen and bath-room (fig. 6.1). Useful area : 75,5 m^2
- Price : 2 300 F per m^2 (of useful area)
- Areas of the various elements
  - Floors :

Room 1	12	m^2
Room 2	11,5	m^2
Living-room ..	23	m^2
Hall	10	m^2
Corridor	5	m^2
Kitchen	10	m^2
Bath-room and Toilet ...	4	m^2
	75,5	m^2
Landing	15	m^2

Fig. 6.1 - Plan of the flat selected for the economic study



- Outside walls .... 88 m^2
- Inside walls: Room 1-Room 2 .... 10 m^2
  Room 2-Bathroom .. 5,5 m^2
  Room 1-Corridor .. 3,5 m^2
- Doors : Entrance .... 2 m^2
  Room 1, Room 2 ... 1,5 m^2
- Windows : Room 1, Room 2, Kitchen ... 2 m^2
  Living-room ...... 6 m^2
- Height under ceiling .... 2,5 m
- Heating : Central. Total heating volume for building is 7 000 m^3. Five radiators in the reference flat.

6.2.2 -Construction Details of the Reference Flat

6.2.2.1 - Partitions :

- Outside walls and separating walls :
  - 15cm solid parpen
  - 2 x 1,5 cm plaster coating
- Floors
  (ceilings)
  - 12 cm reinforced concrete
  - 3 cm cement screed
  - 1,5 cm plaster
- Inside walls
  - 4 cm hollow brick
  - 2 x 1,5 cm plaster coating

6.2.2.2 - Floor Coverings :

- Living-room, rooms, hall : long-pile carpet
- Kitchen and bathroom : PVC on soft underlay

6.2.2.3 - Doors and Windows

Window : "french" type with single glazing (I_a = 28 dB)*

Entrance door : solid wood (I_a = 25 dB)*

(* see appendix C for I_a)

6.2.2.4 - Common Equipment

Lift : Elastically mounted motor and winding gear, on flat roof

Refuse-chute : on balcony, outside flat

Heating : Fuel central heater in basement

6.3 - Variations of basic building to fit the various classes of acoustical comfort

The basic design described in section 6.2 can be altered to fit more or less stringent acoustical requirements. The modifications which have been chosen among technologies available in France, are described in table 6.1. Even though many options are open to improve acoustical performance, a single solution has been adopted in each case. Moreover, it was assumed that the basic design of the building was free from major errors which would drastically affect acoustical comfort and which would require expensive corrective measures.

6.4 - Detailed cost analysis

The costs, including labour, have been computed for each building component and for each class from the following sources of information :

- for the structure, walls, floors, interior doors, heating and refuse-chutes : the "bordereau général des prix unitaires du bâtiment et des travaux publics"[31] of January 1976 and valid for the Paris area (average prices) was used.

Table 6.1 - Materials and Building Techniques for the Five Classes of Acoustical Comfort

Building Component \ Class	4	3	2	1
Floors	12cm reinforced concrete + 3cm cement screed	14cm reinforced concrete +3cm cement screed + 1,5cm plaster coating	18 cm reinforced concrete +3 cm cement screed + 1,5 cm plaster coating	20 cm reinforced concrete on floating screed (5cm cement on 2 cm glass-wool) + 1,5 cm plastic coating
Outside Walls of Flats	15cm solid parpen ($1800 kg/m^3$) +2 x 1,5cm plaster coating	15cm "plank" concrete	20 cm "plank" concrete	Double wall : - 20 cm reinforced concrete - 8 cm glass-wool - 1,5 cm plaster board
Inside Walls of Flats	4cm hollow bricks +2 x 1,5 plaster coating	12cm solid bricks + 2 x 1,5cm plaster coating	17,5 cm solid bricks + 2 x 1,5 cm plaster coating	Same as 2
Windows	Single windows with normal glazing ($I_a > 28$ dB)	Double glazing $I_a > 33$ dB	Double Window $I_a \geqslant 38$ dB	Double Window $I_a \geqslant 44$ dB
Entrance Door	Solid doors without insulating gasket on 4 sides - $I_a > 25$ dB	Solid door with insulating gasket on 4 sides - $I_a > 30$ dB	Solid door with insulating gasket on 4 sides $I_a > 33$ dB	Solid door with insulating gasket on 4 sides $I_a > 38$ dB
Interior Doors	Solid doors without insulating gasket	Same as 4 except for rooms solid doors with insulation gasket - $I_a > 24$ dB	Same as 4 except for rooms solid doors with insulating gasket	Same as 2
Floor Coverings	Rooms, living-room.entrance, corridor : long pile carpet, kitchen, bathroom: PVC on resilient layer. Common spaces : pavement.	Rooms, living-room, entrance, corridor : long-pile carpet on felt. Kitchen, bath-room, common spaces : PVC on resilient layer.	Rooms, living-room, entrance, corridor : long-pile carpet on felt. Kitchen, bathroom :4cm floating screed, on 1,5cm glass wool Common spaces : neoprene carpet	Inside dwelling : irrelevant common spaces ; steps independent of structure Landing : floating screed
Heating (1)	-	-	-	-
Refuse-chute	Outdoors, single emptier	Outdoors, single emptier	Outdoors, single emptier	Outdoors, double emptier
Lift (1)	-	-	-	-
Individual Equipment	-	-	-	-

(1) No specifications are given since the economic impact will be negligible

- for windows : average prices from a major manufacturer
- for entrance doors : actual prices from an industrial and building acoustics firm
- for floor coverings : actual prices from a major manufacturer
- for lifts : average prices from two manufacturers

These prices are reported in table 6.2 and are expressed :

in F/m^2 for walls, floors and floor coverings
in F for windows and doors
in F/flat for lifts and refuse-chutes

All prices are understood net of taxes.

6.5 - Total Cost per Class of Acoustical Comfort

The total cost P_1, corresponding to the materials and labour of all the components which influence acoustical comfort, can be computed from table 6.2 and section 6.2.1. The result is reported in table 6.3

The cost P_2 of all the components which do not affect acoustical comfort are also shown. It is the same for classes 4 through 1 and it is computed from the average price per square meter of 2 300 F (net) in the Paris area for class 4. The data is derived from 24 housing projects near Paris. For class 5, which is used only to describe ancient habitat, P_2 is set at 1 550 F/m^2 ; it corresponds to the cost of low rent, government subsidized housing (HLM).

From the total cost of buildings, $P_1 + P_2$, for each class, the price differences between classes have been evaluated.

The cost of improvements of heating and of individual equipment such as plumbing and piping have not been defined precisely since their impact on the overall cost of a building has been shown to be negligible.

Table 6.2 - Detailed Cost Analysis

Component \ Class	5	4	3	2	1
Floors	101 F/m^2	111 F/m^2	133 F/m^2	145 F/m^2	172 F/m^2
Outside walls	79 F/m^2	82 F/m^2	100 F/m^2	114 F/m^2	194 F/m^2
Inside walls	45 F/m^2	45 F/m^2	76 F/m^2	94 F/m^2	94 F/m^2
Windows	3 x 300 F 1 x 600 F	3 x 400 F 1 x 800 F	3 x 480 F 1 x 960 F	3 x 600 F 1 x 1 200 F	3 x 800 F 1 x 1 600 F
Entrance door	400 F	1 040 F	1 040 F	1 100 F	1 135 F
Inside doors	2 x 266 F	2 x 266 F	2 x 300 F	2 x 500 F	2 x 500 F
Floor coverings	20 F/m^2 everywhere	Rooms, living-room, entrance, corridor :20F/m^2 Others :30F/m^2	40 F/m2 everywhere	Common Spaces 40 F/m^2 Others : 50F/m^2	Common Spaces 50 F/m^2 Others :20F
Common Equipment: Heating ⁎	-	-	-	-	-
Common Equipment: Refuse-chute	533 F/flat	533 F/flat	587 F/flat	650 F/flat	650 F/flat
Common Equipment: Lifts	1 250 F/Flat	1 275 F/flat	1 275 F/flat	1 275 F/flat	1 275 F/flat
Individual Equipement ⁎	-	-	-	-	-

⁎ See section 6.5

Table 6.3 - Cost of Acoustical Comfort per Class (in French Francs) for a three room flat of 75.5 m^2

Component	Area m^2	5	4	3	2	1
Floor	75.5	7 625	8 380	10 041	10 947	12 986
Outside Walls	88	6 952	7 216	8 800	10 032	17 072
Inside walls	19	855	855	1 444	1 786	1 786
Windows	-	1 500	2 000	2 400	3 000	4 000
Entrance door	-	400	1 040	1 040	1 135	1 135
Inside doors	-	532	532	600	1 000	1 000
Floor coverings	75.5 60.5 15 15	1 510 - - 300	- 1 210 450 450	- 2 420 600 600	- 3 025 750 600	1 510 - - 750
Heating	See remarks section 6.5					
Refuse-chute	-	533	533	587	650	650
Lifts	-	1 250	1 275	1 275	1 275	1 275
Individual Equipment	See remarks section 6.5					
P_1		21 457	23 941	29 807	34 200	42 164
P_2		-	149 709	149 709	149 709	149 709
$P_1 + P_2 = P$		117 025 (1 550 F/m^2)	173 650 (2300F/m^2)	179 160	183 909	191 873
Deviation ΔP (ref.class 4)		33%	0%	3.2%	5.9%	10.5%

For instance, in a financial assessment of the French "Label de Confort Acoustique" [(32),(33)], performed at Creil on 86 dwellings, it was shown that the cost increment between an ordinary dwelling and a flat of high acoustical quality was merely 0,12% for the heating system and 0,08% for plumbing and piping of the total price per m^2.*

* The French "Label de Confort Acoustique" sets a maximum level of 25 dB(A) in the major rooms of a flat for noise generated by collective equipment, which would correspond to class 2. The following precautions were taken for the heating system :

b) Soft and elastic mountings of the heater's pipes
c) Heater on insulated foundation (5 cm glass-wool)
d) Leakproof and elastic mountings of pipes through walls
e) All floors with floating screeds

The cost increment corresponding to these measures was 1,56 F/m^2 (1972 value) or about 0,12% of the total cost.
The cost of improvement of piping and plumbing was 1.11 F/m^2 (1971 value) or about 0,08% of the total cost of living spaces.

7 - Conclusion : The Uses of a Classification of Acoustical Comfort in Housing

7.1 - General Considerations

In attempting a study of acoustical comfort in housing, the European Community has chosen to provide in a first step a uniform technical language. It is to be used in the future to set performance goals thereby contributing to the improvement of housing quality and, more generally, to a better quality of life.

In the present work, the following points have been studied :

A common definition and language of acoustical comfort were established and used to compare the various national requirements and recommendations in effect within the Community. Five classes of acoustical comfort were then designed around class 3, the "minimum recommended legal class". Classes 1 and 2 describe the better grades of comfort, while classes 4 and 5, with their low requirements, are used to rate old housing.

It remains to be seen what the assets of such a classification may be, what would be its consequences and how such a system could be applied.

7.2 - Assets and Effects of the Classification

The main advantage of the classification of acoustical comfort in housing that has been presented above it to provide a common and complete technical language : it would unify, if adapted broadly, the parameters, the criteria and the measurement methods.

The differences which exist between the various evaluation methods of acoustical comfort in housing are not so important that the implementation of a unique system would not be feasible. By introducing a common system, one would boost technical and scientific exchanges and, above all, would facilitate the circulation of products and services throughout the community. Most of the techniques and materials, which are rated for acoustical quality in one of the European countries, are not used uniformly throughout the Common market : usually, they would have to receive the "acoustical" stamp of approval in a country, i.e. be rated according to the relevant national method, before becoming a competitor to local products.

A unified rating system of acoustical comfort, to be effective, would then require the use of uniform laboratory control methods, which, when used by any recognized testing agency, would yield results that could be used throughout the Community.

In the long run, one foresees that the use of a common method will generate a large pool of information on parameters, criteria, accuracy, annoyance, etc., that will be most useful to the acoustical scientists.

The classes of acoustical comfort that have been presented here introduce a concept that is not often part of national methods. It differentiates the acoustical requirements according to the outdoor environment : classes 2 and 3, for instance, may represent a similar acoustical comfort under different circumstances. Classes 2 and 1 define a superior comfort. Classes 4 and 5 have only a subsidiary role : that of describing the acoustical comfort of some existing housing and of housing designed according to criteria less complete than those described here.

Classes 4 and 5 are expected to disappear as the national methods are unified and completed.

Finally, one must reemphasize here that the classes are to be modified when an existing criterion has to be altered or when a new criterion has to be introduced : the system developped here would benefit greatly, for instance, by the introduction of single-number rating methods for quality control, of criteria on vibrations, reverberation times of hallways and staircases, etc. In that sense, the class system is flexible and can be adapted to new developments.

An assessment of the existing national laws and recommendations in the Community indicates that a completely new rating method of acoustical comfort cannot be introduced abruptly. Such a system should be introduced in successive steps over a long period of time.

In a preliminary phase, the introduction of a common technical language in all countries members of the European Community should be encouraged. The "vocabulary" used here is already in use in most countries or would be quite easy to adopt concurrently with a national vocabulary which can always be easily "translated", using programmed algorithms.

In the following step, each country should be encouraged to complete its acoustical comfort criteria to cover all the categories included in the "European" method.

Each country , while adopting the common language, should modulate the use that is being made of the various classes of acoustical comfort according to local constraints such as economic conditions, climate, living habits etc...

Nevertheless, to insure a minimum comfort, each country should be advised to enforce, in the long run, the comfort criteria of the "miminum legal class" number three. To make such a decision more likely, economic incentives could be devised to alleviate the increase in cost due to the adoption of more severe or more complete acoustical requirements.

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Appendix A Octave Band and Third-Octave Band Airborne Noise Insulation Margins M_a and LSM (DIN).

The determination of the transmission loss R according to ISO R 717-1968 (E)[29] has shown that different results obtain when calculations are performed from octave band or third-octave band data. This affects also the values of the airborne sound insulation index I_a and of the insulation margin M_a.

To investigate this problem, ten transmission loss third-octave band spectra have been selected for a variety of materials and building techniques. For each of them, the octave and third-octave-insulation margins M_{ao} and M_{aT} have been computed. M_{aT} is defined for 16 bands centered on frequencies from 100 to 3150 Hz while M_{ao} covers octave-bands from 125 to 2000 Hz.

To convert a value of R calculated from octaves (R_o) into the third-octave value (R_T), the relationship is :

$$R_o = -10 \log \left[\frac{1}{3} \sum_{i=i}^{3} 10^{-0,1\, R_{Ti}} \right]$$

where, R_o is the transmission loss for a given octave band.
and R_{Ti} is the transmission loss for each of the third-octave-bands within the relevant octave band.

The results of this comparison are given in table A.1.

A similar comparison was performed for the insulation margin LSM, defined in the German standard DIN 4109 [7], which is identical to the ISO method except that it does not set a limit on the maximum unfavourable deviation : ISO R 717 allows a maximum deviation of 8 dB for measurements in third octave bands and of 5 dB for measurements in octave bands.

Because of differences in the frequency ranges covered, some deviations between third-octave and octave band results occur if the thrid-octave band centered on 3150 Hz "contributes essentially to the mean or the maximum deviation". In practice as Table A.1 shows, these corrections are exaggerated if the 8 dB or 5 dB rules are applied.

These problems explain why the definition of DIN excludes the maximum unfavourable deviation(30) of ISO.
For the same reasons, this rule has not been included in the "modified-ISO" model

Table A.1 - Octave Band and Third-Octave Band
Airborne Sound Insulation Margins
Examples

Case N°	Type of Construction	Margin M_a			Margin LSM		
		M_{a_T}	M_{ao}	ΔM_a	LSM_T	LSM_o	ΔLSM
1 xx	1,5mm Aluminium sheet 2mmm Moltacryl 73mm Moltopren-hard } 2x	- 30	- 32	+ 2	- 25	- 28	+ 3
2 xx	Double glazing (24mm) in sealed metal frame	- 20	- 23	+ 3	- 20	- 20	0
3 xx	Double glazing (24mm) in "openable" frame	- 22	- 24	+ 2	- 22	- 22	0
4	Double partition in 25 mm plasterboard	- 5	- 6	+ 1	- 5	- 6	+ 1
5 x	Plaster +10cm Ytong + 5mm glass wool + 15 cm Ytong + Plaster	+ 1	- 1	+ 2	+ 2	+ 2	0
6 xx	- 15cm concrete - 22cm Styropor - 15cm concrete	+ 2	0	+ 2	+ 2	+ 2	0
7	5 cm light concrete plastered on one side	- 16	- 16	0	- 16	- 16	0
8 xxx	- 30cm brick plastered (dry) on both sides	- 3	- 2	- 1	- 3	- 2	- 1
9 xx	- 24 cm hollow brick plastered on both sides	- 2	- 3	+ 1	- 2	- 2	0
10	8 cm concrete	- 6	- 6	0	- 6	- 6	0

* Cases where the transmission loss spectra R' have dips larger than 8 dB in any third-octave band or 5 dB in any octave band.

** Cases without dips of 8 dB in third-octave bands but with dips larger than 5 dB in octave-bands.

*** Case where the difference between third-octave and octave band margins is due to the measured value in the third-octave band centered at 3150 Hz.

Appendix B Translating National Requirements for Airborne Noise and Impact Sound Insulation into a Common System

B.1 - Airborne Noise Insulation between Dwellings and Houses

The standard ISO/R 717-1968 (E)[29] has been used with some modifications for the evaluation of the Airborne Sound Insulation Index I_a and the Airborne Sound Insulation Margin M_a. The principle of the calculation is the following.

For each third-octave band, between 100 and 3150 Hz or for each octave band between 125 and 2000 Hz, one measures "in situ" the normalized level difference.

$$D_{n,T} = L_1 - L_2 + 10 \log \frac{T}{0,5}$$

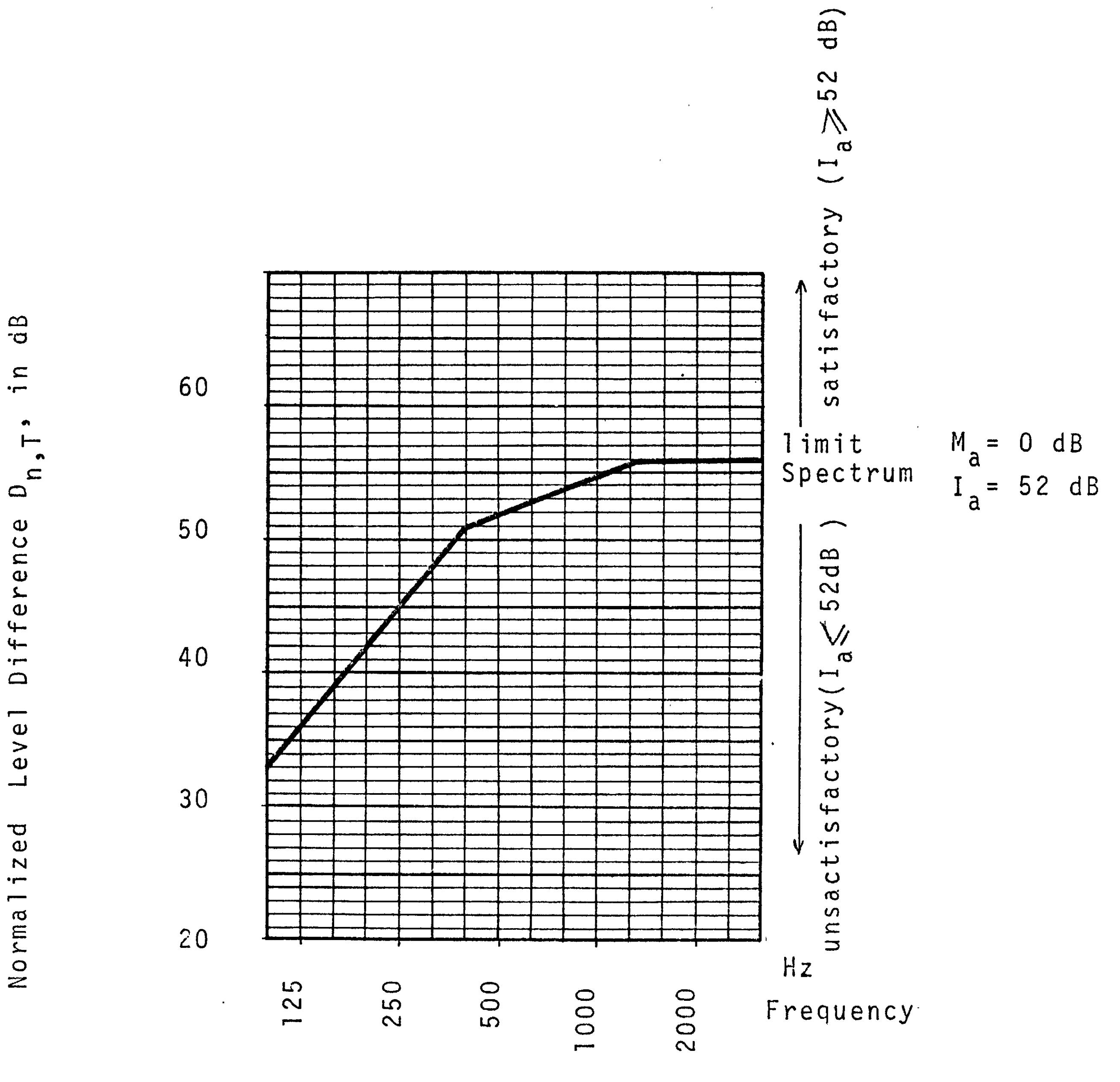
The spectrum obtained is then compared to a reference curve (fig. B.1), identical to the reference curve prescribed by ISO/R 717-1968 (E), which corresponds to an airborne sound insulation index I_a = 52 dB and to an airborne sound insulation margin M_a = 0 dB.

The reference curve is then shifted in steps of 1 dB towards the measured curve until the following condition is satisfied : the mean unfavourable deviation, computed by dividing the sum of the unfavourable deviations by the number of measuring frequencies, is greater than 1 dB but not more than 2 dB.

The airborne sound insulation index is the value of the shifted curve at 500 Hz or the insulation margin M_a is equal to the number of dB's by which the curve has been shifted with :

$$I_a = M_a + 52 \text{ dB}$$

Fig. B.1 - Reference Values for Normalized Level Difference ($D_{n,T}$)



The additional requirement of ISO/R 717-1968 (E) on the maximum unfavourable deviation is lifted (cf. Appendix A).

The methods of evaluation of insulation in use in Europe are compared to the above method called "modified-ISO", in the following sections.

B 1.1 - Belgium

The requirement of NBN[6] specifies , for airborne noise insulation, a region within which the normalized insulation $D_{n,T}$ measured "in situ" must fall. There are five regions (I,II,III, IVa and IVb) bordered by five spectra (1, 2, 3, 4a and 4b) (fig.2.3).

The airborne noise insulation which is required between dwellings corresponds to a spectrum located in zone II, with a permitted tolerance if the mean of unfavourable differences does not exceed 1 dB within each of the frequency ranges : low (100 to 315 Hz), medium (400 to 1250 Hz) and high (1600 to 3150 Hz).

The Belgian requirements for zone II correspond to M_a = - 1 dB

B.1.2 - Federal Republic of Germany

The reference curve of the German Standard DIN 4109 [7] and of the present study are the same (see fig. 2,1) and the definitions of LSM and M_a are almost identical. In practical cases, the minor differences which have to do with the computation of insulation margins from third-octave band values have no or little impact on the end result. One can in general assume[15] :

$$LSM \approx M_a$$

$$R_W \approx I_a$$

B 1.3 - Denmark

The Danish regulation[8] defines, as ISO and DIN do, a maximum spectrum which limits the transmission loss R measured "in situ" (see fig. 2.5). However, the reference curve is not used to compute an insulation margin : the requirement is that the mean deviation between reference and measured spectra does not exceed 1 dB.

The reference curve selected in the present work, when compared to the Danish method, would be 2 dB more severe. Therefore a value of M_a of - 2 dB, or even - 3 dB if the error of 1 dB over 16 third-octave bands is included would be acceptable by Danish standards.

But since they are differences between the Danish and "modified-ISO" methods on the permissible mean deviations (resp. 1 dB and from 1 to 2 dB), the Danish requirement for airborne noise insulation between dwellings is found to correspond to M_a = - 1dB.*

B 1.4 - France

From the NF standards [9] and the law of June 14, 1969[9] which sets the level of acoustical comfort in housing, it is possible to derive a maximum spectrum for the airborne noise normalized insulation $D_{n,T}$ (fig.2. 6. curve 5). Since the emitted and received noise levels are defined in the law, one can find a minimum insulation.

Conversely, one can compute, from the reference curve chosen in this project, M_a = 0 dB, the A-weighted sound pressure level that would be measured in the "receiving" room when the "emitted" sound pressure levels in the adjoining dwelling, are 80 dB in each octave-band from 125 to 4000 Hz. The result would be 33 dB(A) that is 2 dB better than the French requirement.

* New building noise control requirements are expected to be issued in Denmark by the end of 1977 [48]. They should correspond to M_a = 0 dB

Then, the normalized insulation $D_{n,T}$ or the transmission loss could be 2 dB under the value selected in section B.1, provided the area of the separating wall is between 8 and 12 m^2 and the volume of the emitting room is between 24 and 36 m^2 (M_a = - 2 dB) ; it would still satisfy the French maximum level of 35 dB(A).

If the tolerances allowed by both the French and "modified-ISO" methods are taken into account, even a poorer insulation would do. The maximum level permitted by French standards, is 35 + 3 = 38 dB(A) to account for measurement uncertainties : a spectrum similar to the one selected, but depressed by 5 dB (M_a = - 5 dB) would still suffice. If the mean unfavourable deviation of ISO, between + 1 and + 2 dB, is entered, a value M_a = - 8 dB would still lead to a measured level of 38 dB(A).

Nevertheless, if one considers the average deviation between the margins LSM or M_a [25] and the French method for several types of insulations (cf. Appendix A, fig. A.1), which shows :

$$LSM = M_a(\text{ISO-modified}) = R\,[\text{dB(A)}] - 1$$

$$I_a = M_a + 52 \simeq R + 51$$

The conclusion is that the French requirement relative to airborne noise insulation between dwellings is equivalent to an insulation margin $M_a \simeq -2$ dB and to an airborne sound insulation index I_a = 50 dB.

B 1.5 - Great Britain

The British standards[10] require minimum spectra of the normalized insulation $D_{n,A}$ measured "in situ" between two dwellings or two houses (grade I, grade II and house party wall grade)(fig.2.4). A negative deviation from these spectra, corresponding to a lack of insulation , is allowed provided their sum over the 16 third-octave-bands does not exceed 23 dB.

The reference spectrum (M_a = 0 dB) used here is found sufficient, by British standards, for the insulation between two flats or two houses. A spectrum similar but lower by 1 dB (M_a = - 1 dB) would also be sufficient, at least for apartments (grade I). A spectrum shifted even lower (M_a = - 2 dB) would not be satisfactory since the sum of the unfavourable deviations would be 25,5 dB.

The British requirements can be expressed as :

Between 2 flats (grade I)	between houses (house party wall grade)
M_a = - 1 dB	M_a = 0 dB
I_a = 51 dB	I_a = 52 dB

B 1.6 - The Netherlands

The Dutch standard[11], unlike others does not define a minimum spectrum for the Normalized Level Difference $D_{n,T}$, but sets values for the frequency bands centered on 125, 250, 500, 1000 and 2000 Hz (see fig. 2.2.). The computation of the insulation margin (I_{lu}) is derived from the differences between the values of $D_{n,T}$, measured "in situ" and the required values. Three parameters are used (rounded to the nearest integer :

- a : the mean of positive and negative deviations
- b : the most favourable deviation plus 4 dB
- c : the average of the two least favourable deviations plus 2 dB

The margin I_{lu} is the smallest number among a, b, c. For the "modified-ISO" spectrum (M_a = 0 dB), I_{lu} = + 2dB . The reference spectrum chosen for this study is 2 dB above the Dutch requirement (I_{lu} = 0 dB). The spectrum could be shifted by as much as - 2 dB and still give I_{lu} = 0 dB.

B 1.7 - Summary

The various standards on airborne sound insulation between dwellings in use within the Community correspond to the following values when expressed in terms of the "modified-ISO" system :

	M_a (dB)	I_a (dB)	
B	- 1	51	
D	0	52	
DK	- 1	51	
F	- 2	50	
GB	- 1	51	(Flats)
	0	52	(Houses)
NL	- 2	50	

B 2 - Airborne Sound Insulation between Dwellings and the the Other Parts of a Building

The insulation requirements between dwellings have been chosen as the basis for the evaluation of the insulation requirements between dwellings and :

- common circulation spaces
- industrial, commercial or workshop premises

For instance, , it was established that according to French law(9) , which requires a level of 35 dB(A) inside living areas if levels of 80 dB are emitted in each octave , an airborne sound insulation index I_a of 50 dB is required. Since it also calls for 35 dB(A) inside dwellings if 70 dB is emitted in each octave in common circulation spaces I_a between dwellings and common circulation spaces must be 40 dB.

Following a similar procedure, we have computed all the I_a indices relative to existing national regulations.

B 3 - Impact Sound Insulation between Dwellings

The ability of a floor to insulate against the transmission of impact noise is expressed by the Impact Sound Insulation Index I_i and the Impact Insulation Margin M_i [29].

The procedure used to determine these indices is the following. Using a normalized impact source, the tapping machine,[24] one measures in each octave band or third-octave band, the sound pressure level L in the room below to obtain the normalized impact noise level $L_{n,T}$ defined as :

$$L_{n,T} = L - 10 \log \frac{T}{0,5} \quad \text{in dB}$$

where T is the reverberation time in the band under consideration in the receiving room in seconds.

The spectrum of $L_{n,T}$ is then compared with a reference spectrum (fig. B.2) corresponding to $M_i = 0$ and to $I_i = 65$ dB. Note that the reference spectrum is expressed in octave bands. If the measurements of $L_{n,T}$ are in third-octave band, the result must be translated into octave band values before comparing to the reference curve.

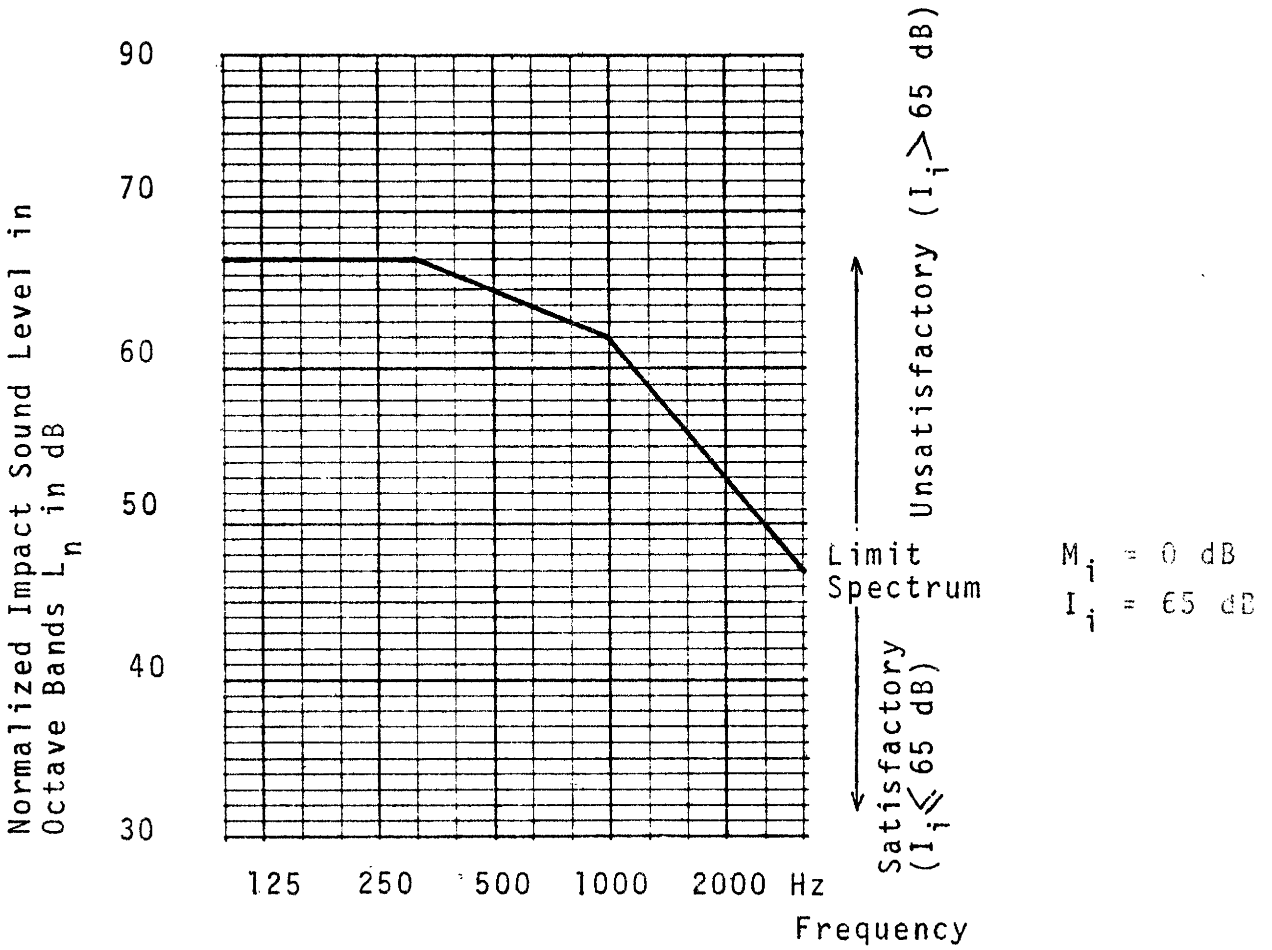
Note that the interpretation of figure B 2 is converse to that of figure B1, the satisfactory area being the lowest.

The unfavourable deviations (i.e. positive) can then be determined from the measured and reference spectra; their mean is computed over the 16 third-octave bands or five octave bands. If the mean deviation is not between +1 and +2 dB, the spectrum is shifted by steps of 1dB until this result is achieved. The number of dB steps of the shift is equal to the impact protection margin M_i. If needed the impact sound insulation index I_i can be obtained from :

$$I_i = M_i + 65 \quad \text{dB}$$

Therefore, the better the floor, the larger the margin M_i and the smaller the index I_i. This definition can be used to compare the various national methods.

Fig. B.2.- Reference Values of Normalized Impact Sound Level L_n



B 3.1 - Belgium

For three limiting spectra (1,2,3) [6] for the zones I,II and III of impact noise acoustical comfort (fig.2.10), the following values of M_i and I_i obtain :

Limit spectrum	M_i (dB)	I_i (dB)
1	+ 10	55
2	0	65
3	- 10	75

Note that the Belgian requirements vary according to the nature of the receiving and emitting rooms : they are more severe, for instance, between the bathroom of a flat and the bedroom of another than between two kitchens.

B 3.2 - Federal Republic of Germany

The definition of the impact sound insulation margin TSM [7] is identical to that of M_i. The maximum deviation allowed is identical and the reference curves are parallel. However, the minimum comfort required by DIN 4109 (TSM = 0 dB) is lower than that proposed for M_i. Then,the German reference conditions of impact noise insulation can be expressed as :

$$M_i = -1$$
$$I_i = 66 \text{ dB}$$

B 3.3.- Denmark

The Danish regulation [8] defines a reference spectrum in third-octave bands. To compare it to the ISO octave band spectrum, it must be shifted upwards by 5 dB. The comparison shows that the "modified-ISO" system is less severe than the Danish system which is characterized by :

$$M_i = +3 \text{ dB}$$
$$I_i = 62 \text{ dB}$$

B 3.4 - France

The French law [9] specifies a maximum A-weighted sound pressure level (70 dB(A)) in the receiving room, when the tapping machine is operated in the emitting room. An infinity of spectra can be found to correspond to this 70 dB(A) level. For instance, the reference spectrum of the DIN method corresponds also to 70 dB(A) (the"modified-ISO" system corresponds to 67 dB(A)). The spectrum chosen to represent the French system in figure 2.12 is the maximum spectrum corresponding to 70 dB(A); the shape of this spectrum is unfortunately remote from reality.

Under those conditions, it is not possible to investigate seriously the equivalence of the French and modified-ISO methods, without extensive experimentation. However, it corresponds approximately to M_i = - 7 dB (I_i= 72 dB).

B 3.5 - Great Britain

The impact sound insulation margin M_i computed for the grade I curve [10] relative to impact noise insulation between flats is :

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

with

$$I_i = 65 \text{ dB}$$

B 3.6 - The Netherlands

The shape of the Dutch NEN 1070 [11] standard for impact noise rating is quite different from the form used in the other standards. The method used here to compare standards applies poorly to this case. However, if rated against the "modified-ISO" method, it corresponds to :

$$M_i = -7 \text{ dB}$$
$$I_i = 72 \text{ dB}$$

B 3.7 - Summary

When expressed in the "modified-ISO" system, the national requirements for impact noise insulation are :

	M_i (dB)	I_i (dB)
B	- 10 0 + 10	75, 65, 55
D	- 1	66
DK	+ 3	62
F	- 7	72
GB	0	65
NL	- 7	72

B.4 - Impact Sound Insulation between Dwellings and the Other Parts of a Building

The impact sound insulation index I_i between dwellings has been used as the basis for the evaluation of impact noise requirements between dwellings and common circulation spaces and industrial, commercial and workshop premises.

For instance, the impact sound insulation margin TSM of DIN 4109[(7)] which is + 3 dB to 0 dB between dwellings corresponds to values of I_i of 65 and 68 dB respectively. Then the insulation margin TSM = + 20 dB required by DIN 4109 between dwellings and cinemas, restaurants,shops and other similar premises would correspond to :

$$I_i = 68 - (20 - 0) = 48 \text{ dB}$$

Appendix C : Computation of the Airborne Insulation Indices I_a of Windows, Entrance Doors and Room Doors

C 1 - Introduction

In section 3, the insulation against outdoor noise and against airborne noise from common circulation spaces were not defined in terms of the acoustical characteristics of windows and entrance doors. The former was defined in terms of an equivalent level L_{eq} not to be exceeded within dwellings, the latter was defined in terms of the overall insulation of outside walls and entrance doors, independently of their respective areas and acoustical properties.

An additional computation is then needed to define the insulation properties of doors and windows. It will be performed in appendix C and will use the data on a reference flat described in section 6.

C 2 - Computation of the Insulation of Windows

As indicated in sections 2 and 3, the German recommendation VDI 2719[15] was used to define the insulation against outdoor noise. It has been in use for some time and tested on practical cases and it should become a federal standard soon[21].

The insulation index of a window is defined as :

$$I_a = R_w \simeq L_{Aa} - L_{Ai} + 10 \log \frac{S}{A} + 5 \qquad \text{(C 1)}$$

where :

R_w is the airborne sound insulation index (called I_a) is the ISO-modified system)

L_{Aa} is the equivalent level in dB(A) in front of the building

is the indoor equivalent level in dB(A)

S is the area in m^2 of the windows

A is the equivalent absorption area of the receiving room in m^2 (usually $A \simeq 10\ m^2$ in dwellings)

5 dB corresponds to a correct factor taking into account the spectrum of traffic noise [(15)(44)] which peaks in the octave-band centered on 500 Hz. Since the index R_w, as well as I_a, was defined for a uniform spectrum, it was necessary to raise R_w, by 2 dB according to Gösele, by 5 dB here for more safety. We should stress here that the French system solves this problem by computing an index R_A for a traffic noise spectrum and not a pink noise spectrum.

In the specific case of the three-room flat described in section 6.2, the parameters are :

L_{Aa} : daytime : 70 dB(A)
nighttime : 60 dB(A)

L_{Ai} ; for class 4 : daytime 45 dB(A) in living-room
nighttime 40 dB(A) in rooms 1 & 2

S living-room : $6m^2$
room : $2m^2$

A living-room : $10m^2$
room : $10m^2$

Then,

I_a or R_w living-room = 28 dB

I_a or R_w room, night = 18 dB

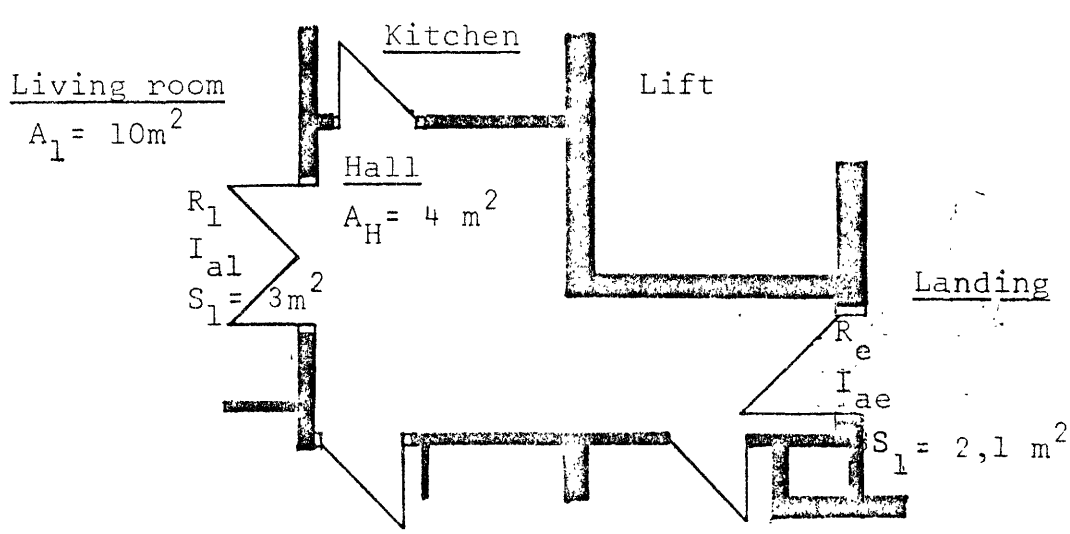
I_a or R_w room, day = 23 dB

Therefore, to reach the acoustical comfort of class 4 for outdoor noise, it would be necessary to install windows with an insulation index I_a of 28 dB in the living-room and 23 dB in the rooms 1 and 2.

C 3 - Insulation Index of Entrance Doors

It will be assumed that the airborne noise insulation between a dwelling and the common spaces depend entirely on the insulation index I_a of the entrance door, with the configuration of Figure C 1.

Fig C 1 - Entrance Configuration



The reverberation time in the hall is 1.0 sec., corresponding to an equivalent absorption area of $4m^2$, with all doors shut. The sound pressure level difference between the hall and the living-room will be [46] :

$$L_1 - L_L = R_1 + 10 \log \frac{A_H}{S_1} + R_L + 10 \log \frac{A_L}{S_L} \qquad (C2)$$

living room respectively and R_1, R_L the transmission losses of room respectively and R_1 , R_L the transmission losses of the doors between landing and hall and between hall and living. The normalized insulation D_{nT} between landing and living-room is :

$$D_{n,T} = L_1 - L_L + 10 \log \frac{T_L}{0,5} \quad \text{in dB} \qquad (C3)$$

then,

$$D_{n,T} = R_1 + R_L + 10 \log \frac{A_H \times A_L}{S_1 \times S_L} + 10 \log \frac{T_L}{0,5} \qquad (C4)$$

The equation is true only for each equation band (i.e. for each octave or third octave band). It is an approximation to generalize it when considering the averag values of $D_{n,T}$, R, A and T (i.e. $\overline{D_{n,T}}$, $\overline{R}$, $\overline{A}$ and $\overline{T}$) over the whole frequency range (i.e. 125 to 2000 Hz), since these parameters are varying from band to band.

i.e.

$$\overline{D_{n,T}} \simeq \overline{R}_1 + \overline{R}_L + 10 \log \frac{\overline{A}_H \times \overline{A}_L}{S_1 \times S_L} + 10 \log \frac{\overline{T}_L}{0,5} \qquad (C5)$$

The two formulas (C4) and (C5) are only identical when the reverberation times in the hall T_H and in the living T_l do not vary extensively with frequency.

Then ,

$$\overline{D_{n,T}} = \overline{R_1} + 10 \log \frac{6,4 \times 12,4}{2,1 \times 3,2} + 10 \log \frac{0,73}{0,5}$$

$$D_{n,T} \simeq R_1 + 12 \text{ dB} \qquad (C6)$$

If we assume that the living-room is a simple door without rubber, with $\overline{R_L}$ = 12 dB the normalized insulation index will be :

$$\overline{D_{n,T}} = \overline{R_l} + 12 + 10 \log \frac{4 \times 10}{2,1 \times 3,2} + 10 \log \frac{0,9}{0,5}$$

$$\overline{D_{n,T}} \simeq \overline{R_l} + 22 \text{ dB} \qquad \text{(C 7)}$$

If the overall insulation index $I_{a,ov}$ and the door insulation index I_{al} are known for each class and with :

$$D_{n,T} \simeq I_{a,ov} - 2 \text{ dB}$$

and

$$R_l \simeq I_{al} - 2 \text{ dB} \qquad \text{(C 8)}$$

we have :

$$I_{a\ ov.} \simeq I_{al} + 22 \text{ dB}$$

The insulation index I_{al} of each door can be computed (table C.1)

Table C 1 - Airborne Noise Insulation Index of Entrance Doors (example)

Class of Acoustical Comfort	Required Insulation between Common Spaces and Flat (dB)		I_{al} of entrance door in dB
	$I_{a\ ov.}$	$D_{n,Tov.(appr)}$	
1	$\geqslant 62$	$\geqslant 60$	$\geqslant 40$
2	$\geqslant 55$	$\geqslant 53$	$\geqslant 33$
3	$\geqslant 52$	$\geqslant 50$	$\geqslant 30$
4	$\geqslant 47$	$\geqslant 45$	$\geqslant 25$
5	< 47	< 45	< 25

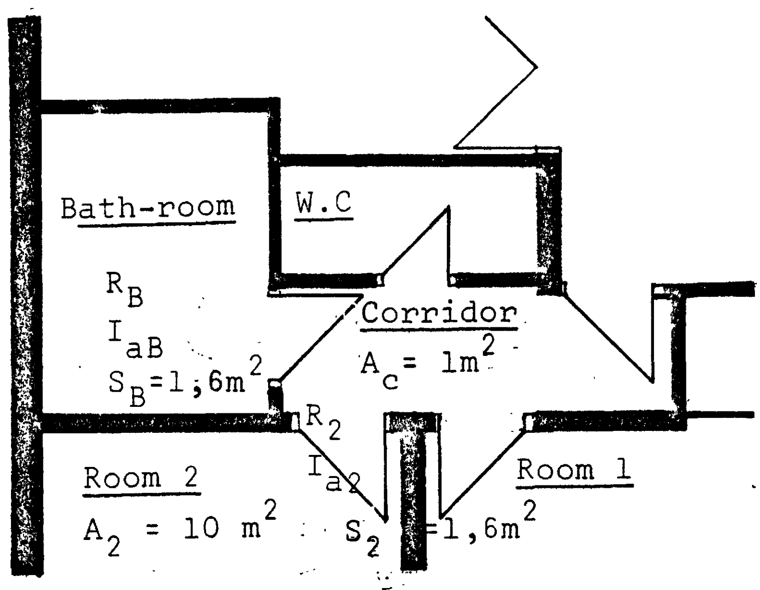
In the example of chapter 6, the living room door has been assumed closed.

C 4 - Insulation Index of Room Doors

The calculation of the insulation between "noisy" areas such as living room, kitchen and bathrooms, follows the procedure described above (cf C3).

In the example of chapter 6, the plan was the following (fig. C 2)

Fig. C 2 : Sound Isolation between Bath-room and Room 2



The normalized level difference $D_{n,T}$ between the bath-room and room 2 is, assuming that the doors are the weakest acoustical elements :

$$D_{n,T} \simeq R_B + R_2 + 6 \text{ dB} \qquad \text{(C9)}$$

or

$$I_{aov.} \simeq I_{aB} + I_{a2} + 6 \text{ dB}$$

where R_B and R are the insulation indices of the doors of the bath-room and of room 2 respectively.

According to the class of acoustical comfort, $D_{n,T}$ will assume the following values :

Class 3 : $I_{a_{ov.}} \simeq 42$ dB

Class 2 or 1 : $I_{a_{ov.}} \simeq 45$ dB

Then, the sum of the indices :

Class 3 : $I_{a_B} + I_{a_2} \simeq 36$ dB

Class 2 or 1 : $I_{a_B} + I_{a_2} \simeq 39$ dB

The problem can then be solved in two ways :

- one can either install two doors with the following characteristics :

  Class 3 : $I_{a_b} = I_{a_2} = 18$ dB

  Class 2 and 1 : $I_{a_B} = 18$ dB, $I_a = 21$ dB

- or one can use a regular bathroom door ($I_{a_B} = 14$ dB) with room doors of higher quality :

  Class 3 : $I_{a_2} = 22$ dB

  Class 2 or 1: $I_{a_2} = 25$ dB

In the economic study of chapter 6, the latter option has been retained since it seems to be less expensive.