Acknowledgement

I am greatly indebted to my thesis supervisor, Dr. Mark Lang, for his valuable guidance and sustained encouragement during the period of this investigation and in the preparation of the thesis, and partial support to the project from NRC grant A9193.

I am especially grateful to Dr. Samir Mattar, whose expert knowledge of developing graphs from computer results and its interpretation, his discussion, advice and encouragement have been invaluable.

I am also grateful to Dr. Richard Guy, whose assistance, valuable criticism, advice and proof reading was inestimable.

My special thanks to:

Prof. Anthony Soda, for giving a great deal of his time and practical experience to ensuring that the cost analysis are correct.

Mr. S. Chockalingam, for his comradeship, interest and encouragement.

Mr. Rashid Mohsini, for the discussions in some aspects of this study.

Those who partook in the typing of this thesis.

Finally, I would like to record my sincere thanks to Dr. Paul Fazio, Director, Centre for Building Studies, for his keen interest in this study and his financial support from les subventions de la formation de chercheur et d'action concertée (FCAC), Gouvernement du Québec.

Table of Contents

List of Tables

List of Figures

List of Figures (Cont'd)

CHAPTER 1

INTRODUCTION

1.1 General

> "Someone soon will write his Ph.D dissertation on the cost to society of soundproofing structures to keep out noises from the street and from skies."
>
> R. A. Baron in "The Tyranny of Noise".

Consideration of cost invariably constitutes a major factor when implementing any new standard in Building Codes. Construction costs are already high and are tending to escalate rapidly. This study attempts to analyze the economic impact of implementing improved noise control standards into building codes for multi-family dwellings. It seeks to identify the relationships between initial housing costs while implementing improved noise control standards and the Community Noise Equivalent Level; also to suggest strategies for improving the living environment provided at known, or possibly reduced, costs through intervention in the structure and content of Noise Control Standards.

The complex question posed is 'What are the cost implications and disbenefits associated with an increase in Noise and Noise Control regulations'? As a way of introducing some of the issues involved and defining the nature of the problem, it is useful to review previous works which deal with the effects of noise in housing.

1.2 PREVIOUS ATTEMPTS TO EVALUATE NOISE

The effects of noise can be summarized as follows (1)

(a) Hearing Impairment;

(b) Sleep Interference;

(c) Speech Interference;

(d) Annoyance;

(e) Degradation of Land use.

This section deals primarily with degradation of land use, and an indepth study of the other topics is outside the scope of this study; however several general issues will be reviewed in the next chapter in order to provide an overall perspective.

The dollar cost of noise in some of its aspects is vague, although certainly real enough, for example, the loss in real estate value is obvious.

In cities, noise is a chief cause of rental turnover in new apartment buildings. Frederick P. Rose(1), president of a New York building management company, says, "of all the complaints owners hear, lack of soundproofing heads the list. And this is borne out by the experience of managing agents from coast to coast".

On Manhattan's Sixth Avenue, one apartment building had its (1) "Apartment Available" sign out for two years because of the subway extension. It reportedly lost $7,000 a month in vacancies and unrenewed leases. Restaurants and shops in this noise-inundated neighborhood also suffered sales losses as office workers and residents detoured to quieter streets. Even banks reported a decline in off-the-street transactions.

The Canadian Government(2) was so concerned about the decline of property values near railroad tracks that it conducted a study of the problem. The research suggested that land zoned "residential" may be developed below its normal value unless it is 500 to 1000 feet from the right of way.

Previous attempts (2) to place a value upon noise annoyance have concentrated upon preferences revealed by changes or differences in land and property values: that is, they have concentrated upon the private housing sector. The majority of these analyses were solely empirical and interpretation of their findings is open to speculation (2). Such studies attempted to show that a differential will exist between the market price of properties with low-noise environments and those with high-noise environments.

The underlying concept of the price differential is that if an environmental nuisance such as noise is newly introduced to an area then some of the more sensitive householders, generally those who value their properties at or a little above their market price, will leave that area. With a distribution of sensitive people which is random in the initial case, more people will leave the areas of higher nuisance than areas less affected. Incomers to the area with their assumed perfect perception will correctly assess the effect of the noise environment on housing utility and thus expect to be compensated by a lower purchase price. Thus a house price differential will develop and continue to develop until the differential accurately reflects the perceived variation of the nuisance (2).

1.3 THE HOUSE PRICE DIFFERENTIAL:

In spite of the attention it has received from environmental economists, the notion of a house price differential has little support from the traditional theories of residential location and urban rents. Moreover, these theories suggest why the house price differential might not be at all readily apparent(2).

The traditional theory of residential location set out in the early 1960's focused upon a trade-off between rents and transport costs. Households substitute transport costs for rent costs with the rate of substitution governed by the households preference for high or low density housing(2). The former costs - transport costs - are regarded as a steadily increasing function of distance from centrally located jobs whilst the latter - rents - are considered to decrease in a similar manner with distance. The reason why rents decrease with distance is that they are supposed to represent a payment for the advantage of proximity. The rent gradient, therefore, is a mirror-image of the transport cost gradiant(2).

Equilibrium conditions in the traditional theory prescribe that, the combined total of a household's expenditure on housing (rents) and transport will be the same at any location. In this context transport costs are seen as the major determinant of the rent gradient, and thus of any differential between the market price of homes.

Recently, encouraged by increasing affluence, environmental quality is gaining added significance in householder's preference functions, (environmental considerations have received more attention in general models of residential location (1).

Generally, housing preferences are considered a function of size of house/plot requirements and environmental tastes; and preferences are maximised within an ability to pay constraint. Transport costs are relevant only in so far as they have a bearing on the ability to pay; in this recent theory travel costs are a secondary determinant. The implication of these 'elements of a new model' is that they prescribe a land value/residential rent surface which is conditioned and moulded by environmental quality. According to recent theory, it could be concluded that good environments are moving upwards in the list of social priorities.

Apart from such obvious implications there is also a more subtle point at issue. Centres of employment (factories, offices, shopping centres) which condition the accessibility surface are often, in addition, sources of major pollution (3). For example, in the case of atmospheric pollution, the National Survey of Air Pollution (Warren Springs Laboratory, U.K., 1972) found that broadly speaking there was a marked tendency for pollution to vary directly with distance from city centres and inversely with density. One might expect a similar relationship to apply in the case of noise pollution because of the systematic variation in traffic densities with distance from the centre or cities. Consequently, the picture that emerges is one where the disbenefits of pollution tend to be highly and positively correlated with the benefits of increased accessibility to jobs, with the one factor partially or completely offsetting the other in their respective effect on the structuring of rent fixation.

To take a specific example and one particularly pertinent to this study, at London (Heathrow) Airport, the work-force had reached 40,000 by 1967(4). Indirect employment in associated activities was much smaller - between 3,500 and 5,000, in 1968(5). Between 73 percent and 83 percent of these employees lived within 10 miles of the Heathrow site, with women, the young and the old, the lower paid, the more menial workers all commuting shorter distances. As a consequence in areas adjacent to Heathrow, at least 10 percent of ~~the~~ resident working men and 5 percent of the resident working women were airport employees(5). Conclude from such figures that the impact on the immediate housing market must have been, and presumably still is, significant, with the degree of this significance declining with both distance from the airport site, and generally speaking, with the level of noise pollution also.

1.4 NOISE PROBLEM IN URBAN HOMES AND MULTI-FAMILY DWELLINGS AND CODE INTERVENTION:

Reviewing the various attempts to evaluate the effects of noise it is evident that we live in an increasingly noisy world and that positive steps must be taken to deal with this problem. The control of noise in single and multi-family structures has become more of a problem in recent years due to(6):

1. The use of lighter construction materials
2. The use of modular partitions which allow quick, easy assembly.
3. The increasing use of glass and open atmospheric concepts in design.

4. The use of mechanized appliances which have become almost standard necessities in the competitive home and apartment market, i.e., dishwashers, clotheswashers and dryers, garbage disposals etc.
5. The increasing popularity of multi-family apartments and townhouses which create high population densities.
6. Lack of attention to detail in the various stages of construction and installation of components.
7. Inadequate floor plan arrangement and acoustical treatment of known inside noise sources; i.e., bathrooms, kitchens, utility rooms, entrance halls and staircases.
8. Improper building orientation in relation to outside noise sources (highways, flight paths) and ineffective use of natural noise barriers (grades, hills).
9. Increased ambient sound level due to increasing ground and air traffic.

The control of noise through building codes has received attention from both municipal and federal agencies. The Federal Housing Administration (U.S.A.)(6) has made comprehensive studies of the noise problem incurred in multi-family dwellings from both inside sources, and outside sources such as aircraft. Among the many Noise Insulation Standards that have gone into effect in the U.S.A. California's Noise Insulation Standards(7) are the most comprehensive to date. However, cost consequences seem to be the stumbling block in implementing these standards.

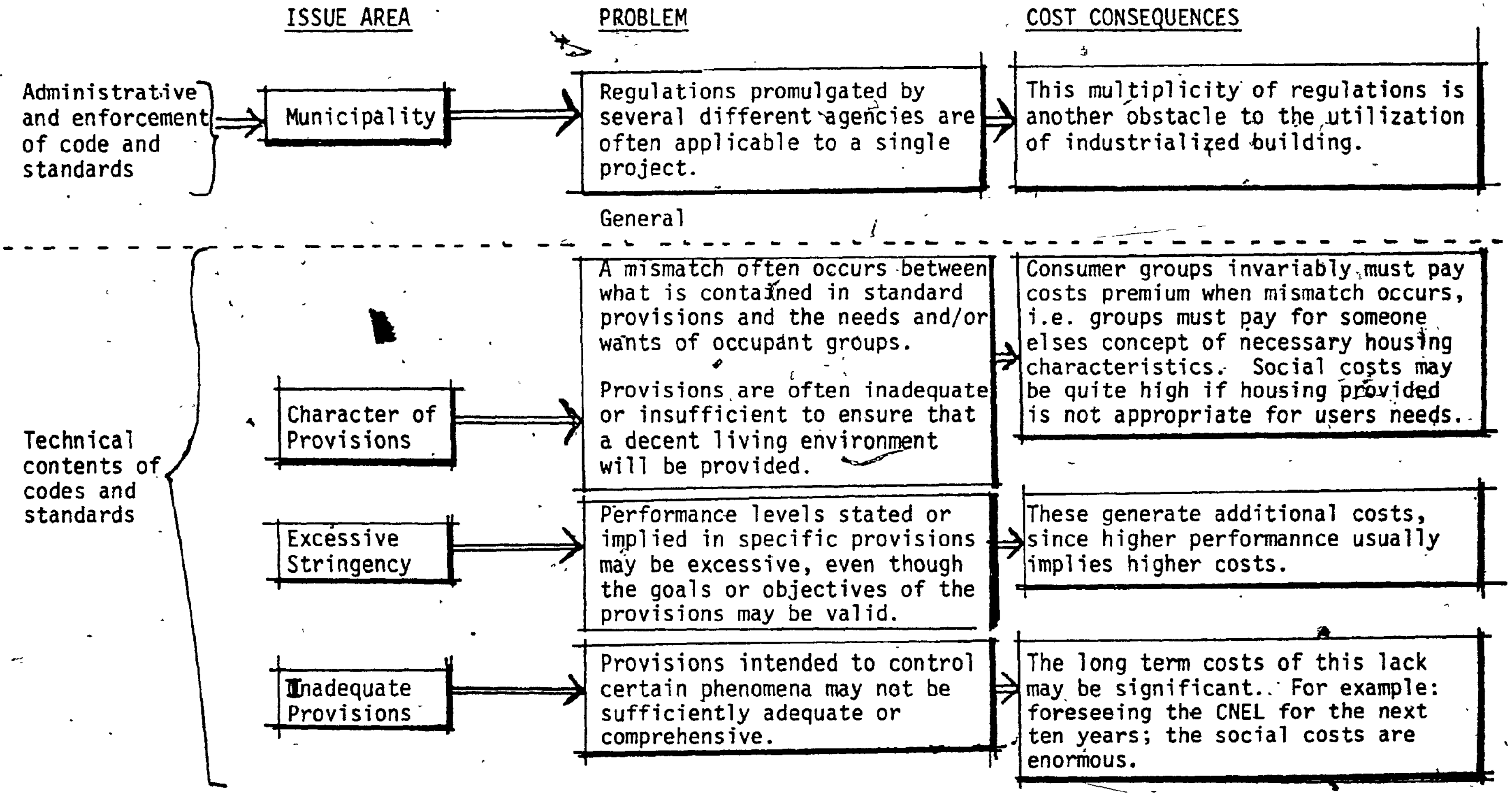
As a way of introducing some commonly held points of view concerning the relationship between housing costs and Noise Control Legislations the diagram shown in Figure 1, places into perspective the viewpoints and conveys an idea of the actual extensiveness of cost issues associated with Noise Control Regulations. The figure briefly summarizes some of the key areas of interest with respect to:

1) The administration, application and enforcement of Noise Control Regulations.
2) The technical contents of Noise Control Regulations.

Due to the general nature of the chart only major issues involved are emphasized.

Administrative and enforcement of codes and standards

ISSUE AREA	PROBLEM	COST CONSEQUENCES
Personnel	Local building officials and inspectors often lack training or qualification.	This lack contributes to the problem of interpretation, etc. Similarily, there is increased resistance to change and/or innovation. Thus the potential of costs savings through technological innovation is reduced.
Inspection	Inspection precedures are often poorly prescribed and slow. Renting apartment building can held up.	The cost consequences of delaying renting are enormous. Where and when building elements are inspected is critical, particularly for industrialized building.
Enforcement	Code enforcement is not always uniform.	Noncomformity often results in poor construction, resulting in high maintenance and/or replacement costs.
Approval of new products & practices	Material oriented noise insulation standards are often charged with being highly resistant to new products or practices.	The potential of cost savings through technological innovation is reduced.
Revisions	Relatively few noise insulation standards are regularly revised and updated by local authorities.	The gradual obsolesence of standards and the attendant reduced potential of utilizing new technological advances clearly increases costs.
Uniformity	A wide proliferation of standards having varying technical contents exists. Local standards in adjacent jurisdictions are often significantly different.	The lack of uniformity in standards is an obstacle to the utilization of off-site produced or of industrialized housing. Panels must be "over designed" to meet all requirements in several noise control standards in intended jurisdictions. It involves high cost consequences.



Regulations promulgated by several different agencies are often applicable to a single project.

This multiplicity of regulations is another obstacle to the utilization of industrialized building.

A mismatch often occurs between what is contained in standard provisions and the needs and/or wants of occupant groups.

Provisions are often inadequate or insufficient to ensure that a decent living environment will be provided.

Consumer groups invariably must pay costs premium when mismatch occurs, i.e. groups must pay for someone elses concept of necessary housing characteristics. Social costs may be quite high if housing provided is not appropriate for users needs.

Performance levels stated or implied in specific provisions may be excessive, even though the goals or objectives of the provisions may be valid.

These generate additional costs, since higher performannce usually implies higher costs.

Provisions intended to control certain phenomena may not be sufficiently adequate or comprehensive.

The long term costs of this lack may be significant. For example: foreseeing the CNEL for the next ten years; the social costs are enormous.

Figure 1 Cost issue associated with Noise Control Standards (8)

CHAPTER 2

EFFECTS OF NOISE

2.1 EFFECTS OF NOISE AND COMMUNITY REACTION

> "The next few years will see significant
> and revolutionary changes upon our planet
> as we struggle to cope with the twentieth
> century's most pressing problems - technology, pollution, alienation, drug addiction,
> education."
>
> -Stephen Truch in official publication
> of The Alberta Teachers' Association
> (May-June 1972)

It seems we cannot escape the unwanted sound that we call noise within. A disturbance to our environment polluting so rapidly as to become one of the major threats to the quality of our lives. The problem knows no political or social frontiers. It affects the socialist countries as much as the United States, Western Europe and Japan, being one of the prices paid for modern industrial development. Great difficulties both of a social and a technological nature must be overcome if noise is to be controlled, and if we are thus to restore to our lives the quality that our very technical successes and economic progress are, ironically, threatening.

Unfortunately, there is no hope that noise will vanish by a technical breakthrough, if only because there is no such thing as a noiseless machine. Of the energy put in to run a machine, some must come out as noise, even if it is a very small fraction. An automobile may have an energy input of 100KW. Of that, only one part in a million, or 0.1W comes out as noise(9). A pneumatic drill may have an input of 3KW of which 1 part in 300 or 1W, comes out as noise(9). Noise control, furthermore, is technically very difficult and very expensive, because it requires large reductions in the acoustic energy emitted by the noise source. For instance, to reduce noise by 3 db 50 percent of the acoustic energy must be removed; to reduce it by 30 db, the energy must be reduced by 99.9 percent(9).

The situation is , in a sense, getting worse, this is so for two reasons. First, machines are more powerful now than they used to be; for instance, a commercial jet liner has a noise power of the order of 10KW(9), versus a power of the order of 0.1KW for a commercial propeller line/ Secondly, we are moving in the direction of modes of living and transportation which inevitably generate more noise.

The effect of multiple causes of noise can, unfortunately, be cumulative. Noise exposure at work adds to exposure while commuting, to exposure at home, and to exposure during leisure activities. Slowly, insensibly, we seem to accept noise - and the physiological and psychological deterioration that accompanies it - as an inevitable part of our lives.

The above deleterious effects of noise on man may be grouped in three categories(10):

(1) Effects that are clear, quantifiable and measurable. For example, hearing loss and cochlea injury following prolonged exposure to intense noise, or reduction of speech intelligibility in the presence of noise.

(2) Effects that are less easily quantifiable because of verbal ambiguity or situational and attitudinal components. For example, noisiness, annoyance and community response.

(3) Effects that are now suspected of occurring or suggested by preliminary observations. For example, decrease in performance, systemeic patho-physiological changes, and sleep interference.

Hearing Loss

The most significant health problem caused by noise is hearing loss. Exposure to audible sound of sufficient intensity for long enough periods of time can produce physiological changes in the auditory system. Some of the impairments are temporary and disappear with time in a quiet environment. A regular schedule of exposure to sounds of sufficient intensity, however, can produce permanent loss of actual auditory receptors. To what extent noise induced hearing loss and attendant cochlea lesions are reversible is not known at present. However, hearing loss or deafness is a crippling loss of one of the most important senses. Deafness can be very slight or complete. There are different legal and medical definitions of deafness. The widely accepted definitions are if the person's threshold hearing level is 25 dB averaged at 500, 1000 and 2000 Hz, then it is known as impaired hearing; if the person's threshold hearing level is 92 dB averaged at the same frequencies then it is total deafness(11). (See Figure 2)

Someone who is hard-of-hearing may have a hearing level anywhere between these two threshold extremes of 25 and 92 db. The average threshold of a non-impaired person is 0 db. In addition, the U.S. Environmental Protection Agency (EPA)(12) specifies the damage effects of noise on hearing in terms of the hearing measured at 4000 HZ.

The EPA rationale is that the ability to hear at 4000 HZ is important to speech communications as well as other auditory functions and the sensitivity of the ear to damage is greater at 4000 HZ than it is at the lower test frequencies. The subject EPA report also took the position that(12):

(a) the maximum amount of damage to hearing from daily exposure to noise could typically be expected to occur at the age of 65, or after approximately 45 years of daily exposure; and

(b) the people in the 90th percentile represent the population of ears most susceptible to noise induced hearing loss.

The noise induced hearing loss not only causes a lowering in the level at which sound is heard, but in many cases causes a loss in hearing quality so that consonants cannot be distinguished and words are confused. In addition, some deaf people also suffer from tinnitus or a ringing in the ears which is disturbing and competes with other sound.

Hearing Loss Caused by Intense Noise

If very intense noise levels of the order of 135db or above at any frequency in the hearing range are experienced, immediate hearing damage is likely to result. However, permanent hearing damage is also produced at much lower sound pressure levels if the noise is experienced over much longer periods (weeks, months or years).

As these are various stages of hearing loss, and a small variation from normal hearing, say 2 db, is unlikely to be noise-induced, we must adopt some rule to define what we shall call the hearing loss caused by noise. According to the American Academy of Opthalmology and Otolarynygology (AAOO) (13) definition of hearing loss, namely one for which the average of the losses at the frequencies 500, 1000 and 2000 HZ is at least 25 db, with respect to the ISO zero. This hearing loss also is the minimum compensable hearing loss in many states in the United States.

A surprisingly large number of people in the United States have noise-induced hearing loss, thus defined. Glorig (14) estimates the number to be 4.5 million. Although 4.5 million is only about one-fortieth of the U.S. population, the number is large. Furthermore, on account of the manner in which noise-induced loss progresses, there will almost always be considerable hearing loss at frequencies above 2000 HZ before the average loss at 500, 1000 and 2000 HZ reaches 15 db. This implies that if the method used to evaluate hearing is dependent upon these higher frequencies, many more people have hearing loss than if the lower frequencies only are used in assessing the loss.

The Burns and Robinson Study and the 1974 EPA Report

Two recent studies are a landmark in our ability to assess risk of hearing damage. The first is a study by Burns and Robinson (1972)(15). The details of the study are perhaps less important than two major conclusions:

- It is no longer necessary to have detailed information about the spectrum of the noise to which people are exposed. Most fortunately it turns out that for a wide range of industrial spectra the simple A-scale weighting is sufficient.

- Integrating the A-scale sound-pressure level over the time of exposure (even for exposure levels varying during the day and for impulsive noises) results in a quantity, the emmission, that correlates extremely well with the hearing damage observed in a large number of workers. Of course, the damage cannot be uniquely predicted. It is only known statistically; thus, an emmission of 121 will produce at 4000 HZ a loss of at least 40 db in 50 percent of the people exposed. Such a loss would, for example, be found in a lumberjack working for five years without ear protection and exposed to 120 dbA from chain saws for 2 hours a day. Further, the odds of loss at 4000 HZ are as follows:

1 in 4	at least 48 db
1 in 10	at least 57 db
1 in 50	at least 67 db

The fact that such tables can now be constructed makes it possible in principle for the first time to suggest to someone contemplating work in a noisy job: "If you do this job, after X years the odds are such and such that things will sound like this to you". Thus he can make a nearly fully informed decision instead of having to rely on experts.

A further important outcome of the Burns and Robinson study is that it makes labelling of the noise-producing devices possible in such terms as "This device produces a sound-pressure level of X dbA at the user's ear. This will cause hearing damage of (such and such severity) in y percent of users, after Z years' use. Wear ear protection".

In 1974 a second important study by the EPA(12) suggests that an equivalent noise level LEQ of no more than 70 dbA over a 24-hour day will protect virtually the entire population. This figure is an average daily energy level. Thus, the energy contained in an 8 hour (a typical work shift) exposure to 75 dbA is equivalent to that contained in a 24 hour exposure to 70 dbA. This assumes that the average level in the rest of the day contributes a negligible amount of energy (it should be less than approximately 60 dbA).

Hence, the amount of sound energy to which the worker is exposed in the community - in traffic, at home and at play - must be considered in establishing the permissible sound level at work. Conversely, the latter must be taken into account in designing environmental noise guidelines for the community.

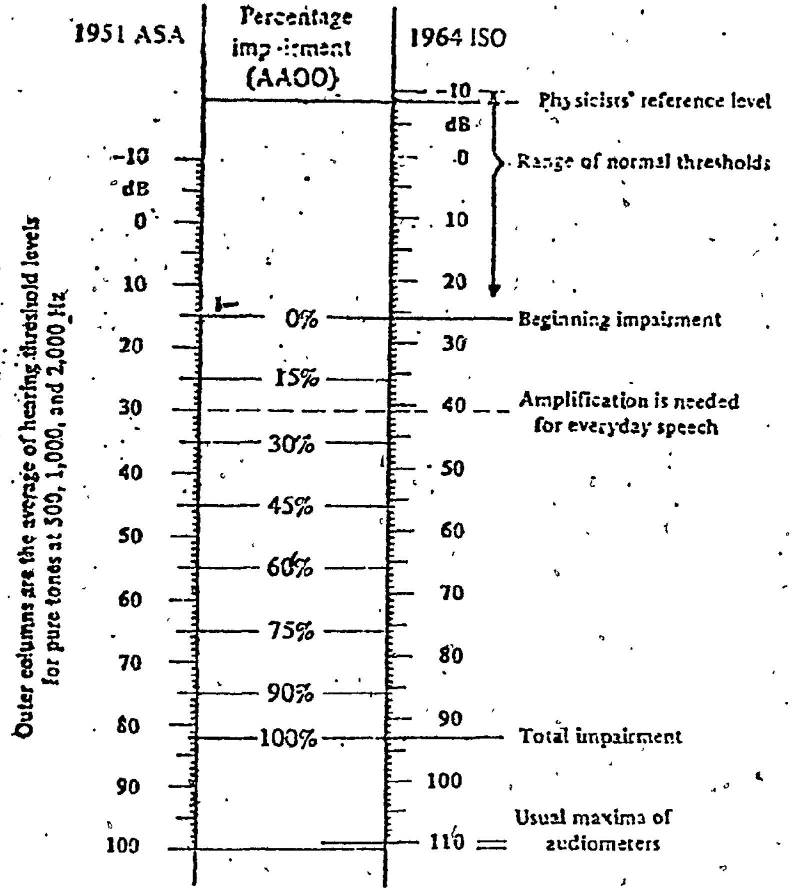


Fig. 2 Average hearing levels and hearing impairment. (From Davis, H. and Krang, F.W., The International Standard Reference zero for pure tone audiometers and its relation to the evaluation of impariment of hearing, J. Speech Hear, Res., 7.7, 1964)

2.2 EFFECT OF NOISE ON SLEEP

Noise can both awaken people and keep them from going to sleep. Airplane noise can be much greater a disturbance to sleep than other noises. The data shown in Table 1 indicates that near a major airport - London (Heathrow)(16) - the number of people awakened by airplanes is about 50 percent greater than the number awakened by other noises (but the number kept from going to sleep is essentially the same). If one takes the London Airport as representative, as many as 40 percent of the people living near major airports may be awakened by noise.

For areas much nearer the airport, the noise level is above 103 PN db, the total percentages are approximately twice as large as other noises. Three percent of the people in a 20-mile diameter around London (Heathrow) Airport live within this band of noise, and are often kept from going to sleep by airplanes. This is clearly an important factor in their lives. By the definition of the World Health Organization, health is a state of complete physical, mental and social well-being, not merely an absence of disease and infirmity, and loss of sleep is a cause of damage to health. In fact, in London (Heathrow) Airport study, about one-fourth of the people kept from going to sleep thought their health was being affected.(17)

Airport and airplane noise is not the only or even the most important source of disturbance to sleep. Automobile traffic noise is particularly significant because of its ubiquitousnes. A study by Thiessen and Olson(18) investigating the effect of truck noise shows that sleeping subjects exposed to a 6-hour tape of a passing truck, with noise in the 40-70 dbA range - a comparatively modest intensity - were usually awakened by a 70 dbA noise. A 50 dbA noise altered the level of sleep in about half of the subjects, as recorded on an electroencephlogram, whereas between 40 to 50 dbA, the chance of awakening the subjects, or altering their sleep pattern was between 10 and 20 percent. These levels of noise at which sleep was affected are considerably lower than previously suspected. In addition they noticed that certain subjects are awakened by a noise of a truck at 40 dbA, where as others are not awakened by a noise of 70 dbA (although changes in the state of sleep, or modifications of the EEG may be observed). Beyond 40 dbA there are 10 chances out of 100 that sleep will be disturbed. (See Figure 3).

According to present information (17), (18), (19) it appears that a sound level inside a house, lower than 60 dbA for airplane noise and lower than 40 dbA for road traffic noise, does not disturb the sleep of the majority of the population. These are very approximate figures, in particular for airplane noise, where one must consider the number of flyovers and their distribution in the course of the night. Generally, in addition to the type of noise and its intensity, the chronology of noise in the course of the night, the alternation of different intensities, and the relation between foreground and background noises also play a considerable role. This has been clearly proven by the experiments of Schieber (19) on the noise of automobile traffic and aircraft. Reduced automobile traffic was found, in some cases, to disturb sleep more than intense traffic with equivalent foreground and background noise. This leads to the conclusion that habit to noise is perhaps easier to achieve when noises are regular and frequent than when they are rare and irregular.

Another experiment of Van Merihelghe (20) proves that sleep can be interfered by noises of 30 to 35 dbA and that noises in excess of 65 dbA are able to provoke the awakening of most people. If the noise is harmonious (such as a Chopin No. 15) even though it is 35 dbA since it is soft and harmonious it won't distrub sleep, but dripping of a tap of the same intensity will interfere with sleep. Here the quality of the noise is the essential factor when it is below 35 db.

According to Van Merihelghe (20), between 30 to 60 dbA of noise exposure will not awaken one, but their physical energy and mental power during the day will be reduced; in other words, recuperation power is reduced.

Habituation to Noises Perceived During Sleep:

From the literatures about habituation to noises it could be said:

> one becomes more easily accusomted to noises of weak intensity than to those of strong intensity(22);
>
> one becomes more easily accustomed to sounds of low frequency than to sounds of high frequency(23);

> habituation is facilitated if nocturnal noises are similar to day noises that one has learned to recognize and for which a veritable "neuronic model" has been formed.

The habituation, however, is strongly "affected" by personal factors such as one's attitude toward a particular noise and one's anxiety concerning the possible effects of that noise on heatlh. Certain persons will suffer more from a disturbance of sleep by a certain noise simply because thay have attached a particular significance to that noise.

Overview:

Several major conclusions can be drawn from the considerations presented in the various literature (17,18,19,20,21,22) concerning the effects of noise on sleep:

1. The extreme heterogeneity of the methods for defining and measuring disturbance, and of the stimuli utilized, as well as the great variability of individual reactions to noise, make an objective definition of a limit of nocturnal noise impossible. This impossibility is accentuated by the gaps in our knowledge concerning the effects of a prolonged disturbance to sleep.

2. Irregular noise and noise which emerges from the background are particularly distrubing to sleep. Indeed the EPA (1974) considers any impulse noise that exceeds the background noise by more than about 10 db A as being potentially sleep distrubing.

3. Noise not leading to behavioural awakening can, however, produce physiological modifications, which in certain cases (such as changes in the stages of sleep) can damage the quality of sleep.

4. Noise occurring toward the end of the night, as well as in the course of dream phases and light sleeping phases, is particularly disturbing. Thus, regulatory measures concerning, for example, the circulation of certain vehicles at night, are bound to be ineffective because the dream periods and the periods of light sleep occur several times a night, at unforeseeable moments; in order to protect these fragile states of sleep it would be necessary to totally suppress the circulation of noisy vehicles during the night.

5. Aged people, women beyond the menopause, sick people, people afflicted with psychic disturbances, as well as children between 4 and 6 years old, constitute a portion of the population who are very sensitive to noise or who could be easily disturbed during their sleep by excessive noises. This particularly sensitive group represents more than one-third of the total population. Thus anti-noise measures should take into consideration the reactions of this important portion of the population, and not only those of "adult males in good health".

6. Laboratory studies have the advantage of permitting a controlled and broader study of diverse technical and physiological variables. On the other hand, they place the subjects in an unfamiliar environment, reconstitute specific noises which are less realistic than those perceived in a dwelling, and do not permit a

study of long-term effects of a prolonged and repeated disturbance to sleep. In any case, laboratory studies, in order to be complete, should include psychometric tests and thorough interviews, in order to reveal the subjective effects of a disturbance of sleep (effects which, as we have seen, can scarcely be over-emphasized).

* * * *

	By Aircraft Noise	By Other Noise
Kept from going to sleep:		
Very often	5%	6%
Fairly often	5	5
Occasionally	11	9
Total	22%	20%
Awakened:		
Very often	5%	5%
Fairly often	8	5
Occasionally	27	16
Total	40%	27%
Rest or relaxation disturbed:		
Very often	5%	5%
Fairly often	7	6
Occasionally	11	12
Total	27%	22%

Table 1: Percentage of people disturbed by aircraft noise and by other sources of noise around London Heathrow Airport (Adapted from McKennell, 1963)

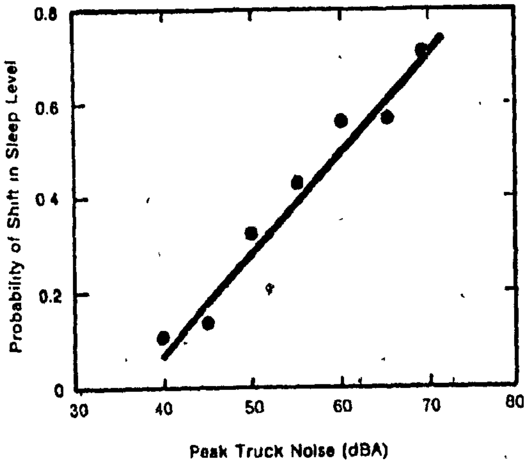


Figure 3: Changes in stages of sleep in relation to noise intensity at the time of the passing of a truck (Canada). Source: Thiessen and Olson, J. Sound and Vibration, 1964, 2(2).

2.3 PHYSIOLOGICAL AND PSYCHOLOGICAL EFFECTS OF NOISE

> "For the Christian, silence is a prerequisite of the spiritual disposition, for in silence he is able to perceive the voice of God. Already in the Old Testament was this connection evident. Often in the New Testament one reads of how Jesus went out into the wilderness.
>
> ...if He, the Son of God, felt a need for silence, He, who ... never fell under the influence of His surroundings, how much more do we need that stillness in order to come before God in silence! Uncounted numbers of men can no longer find this inner quiet amid the daily ever-present noise, and they thereby lack the natural basis for the deeper delving or believing to take place ...."
>
> -Gegen den Lorm (the magazine of the Swiss Noise Abatment League)

The psychology of noise strategy is also evidenced in the Bible in the story of the siege of the city of Jericho where Joshua marched around the cit[illegible]even times with his troops accompanied with the sound of trumpets and cries; and the city fell for the noise and was captured by Joshua.

Even insomnia was known as a disease in ancient Rome caused by the noise of the hammers of the blacksmith, the wheels of the chariots, the cries of the vendors and the public.

According to the experiments carried out by Van Meirhaeghe (20):

1) When one is exposed to noise at the frequency of 3000 to 6000 HZ for longtime regularly a progressive diminishing of acuteness of hearing occurs.

2) If noise is in between 65 dbA to 80 dbA in which case the noise may not cause direct damage to the ear but create physiological problems.

3) If the noise is in between 30 to 65 dbA the manifestation of problems is usually physiological plain by neurosis and irritability it causes; also it may cause secondary psychological effects.

The population of large cities are exposed to the noise of the second and third category above described. Noise in the first category is dangerous to the ear and is very rare in urban environment and if at all found it is a very short duration.

Other Physiological Effects:

Almost everyone has observed that sudden and unexpected noise produces marked changes in the body, such as increased blood pressure, increased heart rate and muscular contractions.

Results of measurements of cardiovascular function in two groups of workers before, after and at work are reported by Shatalov(23). The groups were textile workers exposed to 85 - 95dbA and ballbearing-plant workers exposed to 114 - 120 dbA. The most significant change was a decrease in the maximum blood pressure during work, which was more apparent in the noisy situation. A larger fraction of the workers in the ballbearing plant showed lower heart rates. Noise, even at relatively lower levels, usually tends to constrict the peripheral blood vessel, in fingers, toes and abdominal organs, and to dilate those in the retina and the brain, possibly leading to headaches. Connell(24) cites the case of woodsmen in Sweden working with extremely noisy motor saws. After they go home "their fingers first turn blue, then white. This is the symptom of vasaspostic disease caused when small vessels in the hand constrict so as to cut-off the blood supply", the U.S.

Environmental Protection Agency suggests that there is some evidence of higher incidence of cardiovascular disease (as well as equilibrium disorders and ear-nose-and throat disorders) among workers exposed to high levels of noise(25).

Hormonal Effects:

The work of Levi(26) showed that significant changes have been observed in the urinary excretion of adrenalin and nonadrenalin of subjects for a short time to noise in a simulated industrial situation and to other stimuli. For some individuals the changes bordered on the pathological; it has been suggested that these people are likely to get excited at the least provocation.

In rats, exposure to high-frequency sounds of 20,000 HZ has been reported to radically increased adrenalin excretion(27). Exposure to low-frequency sounds of 150 HZ released oxytocin, a hormone that stimulates the uterus during labor; noise-induced changes in oxytocin level may adversely affect the fetus and the birth process.

Effects of High Noise Levels on the Brain:

There appears to be some measurable effects on the brain potentials of noise-exposed workers, but the long-term effects are not clear.

Changes in the EEG's of the subjects exposed to noise having an SPL of 100dbA with the addition of a tone 3000 - 5000 HZ for 2 - 3 minutes have also been reported(23).

Bell(27) mentions that in neurological studies of Italian weavers their reflexes were found to by hyperactive; in some cases

EEG's showed a diffuse desynchronization similar to that occurring in the psychoneurosis of personality disturbances.

Psychological Effects:

That noise has psychological effects is undoubted. Noises less than 65dbA can influence us in many ways. We can feel annoyed, it may intrude on our sleep, interfere with our activity and our communications.(20) Discontinuous and irregular noises can bother the intellectual work as well as technical activities requiring constant attention, obliging the person to make more effort with greater intensity. Indeed, fears have been expressed that "...over-emphasis on 'damage' may backfire when people come to realize that the truth of the matter seems to be simply that people don't like loud noise and don't like being disturbed".(28) Indeed, people can express violently their dislike about being disturbed by noises. This is recounted vividly by Connell(24).

> "A middle aged woman living in Soho became affected by the incessant noise from a newly open discotheque. She complained to the management, the Police, the local authority but nothing was done to reduce the noise. Her action took the form of suicide. In Italy a 44 year old man took an overdose of drugs because his eleven children made too much noise while he was watching the Olympic Games on television ... In a quiet part of Middlesex with an ambient noise level of 30 to 40 decibles lived Fred, a lusty, healthy builder's labourer. The M4 Motorway was built within a few feet of his cottage home. The resultant traffic caused the noise level to rise to 80 and 90 decibels so this poor man suffered an increase of 100,000 times* in the noise level. He took it for some weeks. Discovered there was nothing he could do about it and his action was also directed against the self. He left a note which read 'The noise; the noise; I just couldn't stand the noise ...'".

---

*This is poetic license.

These are clearly extreme cases of reaction to the intrusion of noise into one's life. But without question the ubiquitousness of the intrusion, even if less severe or loss fatally resented, leads to demands for acoustic privacy which are psychologically no less important than those of visual privacy.

Irritability:

Irritability, tenseness, insomnia are some of the psychological effects of exposure to high levels of noise. It appears, however, that irritability at home is more the result of hearing loss than noise.

A study by the U.S. Navy on the Auditory and Non-Auditory Effects of High Intensity Noise (ANEHIN)(29) on man working on the flight decks of aircraft carriers also observed that "the most common complaints were increased irritability, tenseness, insomnia, and occasionally fear, because of inability to communicate with other men in the presence of noise. With the exception of the difficulty of communication, however, most of the men stated that they did not believe that their trouble was due to the noise. They felt much more strongly that their trouble was due to the general dangers of the job and to further concern about a delay in their return to the United States that had been occasioned by a change in the schedule of operations of the ship".

According to a "standardized interview" workers in very noisy jobs in German industry reported more disturbances of interpersonal relations than workers in slightly noisy jobs.(3)

Psychological Reaction

The character of noise causes emotional and effective changes in the individual. The noise of a family in the neighborhodd may cause a person who is alone to feel isolation and abandonment.(20) The psychological reaction to noise can create a state of nervous tension that is almost permanent accompanied by irritability modification and behaviour and personality problems; it is without doubt a cause of deterioration of human relations between spouses, between parent and child, and between colleagues at work. The situation may eventually lead to agressiveness.

The sources of noise to which people are exposed are categorized in four ways (20)

1 Domestic Noises: eg. T.V.; cleaning apparatus; toilet flushing, etc.
2 Commercial Noises: discotheque, dancing, etc.
3 Neighborhood Noises: building noises that are flanked.
4 Street Noises: vehicles and aircraft noises.

Research shows that the people must be protected from 45 dbA noise during the day and 35 dbA noise during the night(20).

2.4 COMMUNITY REACTION:

In the early 1950's, noise problems near a few military and civil airports in the U.S. motivated the air force and other governmental agencies to investigate aircraft noise and its effect on people in the surrounding communities. This research resulted in the proposal of a model by Rosenblith, Stevens and Bolt (31) for relating aircraft noise intrusion and the probable community reaction. First published by the air force, this model accounted for the following factors:

1. Magnitude of the noise with a frequency weighting for hearing response;
2. Duration of the intruding noise (10 log relative duration);
3. Time of year (windows open or closed);
4. Time of day noise occurs;
5. Outdoor noise level in the community when the intruding noise is not present;
6. History of prior exposure to the noise source and attitude toward its owner;
7. Existence of pure tone or impulsive characteristics of the noise.

Corrections for these factors were generally made in 5dbA intervals, since many of the initial relationships were based solely on the intuition of the authors, and it was considered difficult to assess the response with any greater accuracy.(32) This method was incorporated in the first Air Force Land Use Planning Guide in 1957(33), and was later simplified for ease of application by both the air force and Federal Aviation Administration.

Many methods have been proposed for describing the magnitude and duration of repeated single-event noises with primary application to airport noise problems. Most of these methods represent an evolution of the community noise reaction model, and must embody at least some of its principal factors. Three currently used rating methods are the CNR, the NEF, and Ldn all of which sum the number of events on a 10 $\log_{10} H$ basis, but differ in their assessment of the magnitude of the individual events.

The Composite Noise Rating (CNR)(34), which utilized the maximum Perceived Noise Level (PNL), was introduced in the early 1960's and has been widely used by federal agencies. The Noise Exposure Forecast (NEF)(35) represents an evolution of the CNR and is utilized by some federal agencies for the evaluation of land use compatibility with aircraft noise exposure. Essentially, it updates the CNR by substitution of the tone - and duration - corrected Effective Perceived Noise Level (EPNL), required for jet aircraft certification(36) in lieu of the PNL used in the earlier CNR. Thus, the NEF accounts not only for the maximum noise level but also for both the duration and base tone content of each single sound event, whereas the CNR accounted for only the maximum noise level.

Day/night sound level (Ldn) has been developed by the U.S. Environmental Protection Agency as a general description of environmental noise.(37,38) It is based on the energy integral of the A-weighted sound level, Leq., and thus avoids the complexity of the computer calculations required to obtain EPNL. It accounts for the duration but not for the base tone content of the noise and differs also from NEF by using a 10db rather than a 12db nighttime penalty. Despite these standard differences, however, the difference between the absolute values of Ldn and NEF for specific locations near airports is approximately constant at 35 ± 2db.

The Ldn model has been applied to a series of fifty-five case histories of community noise problems in order to relate the normalized measured Ldn with the observed community reaction. Approximately half the cases involved steady-state industrial and residential noises, and the other half consisted of multiple single event transportation and industrial noises. The results are summarized in Figure 4, with the approximate NEF and CNR scales shown for reference.

The no-reaction response in Figure 4 corresponds to a normalized outdoor Ldn ranging between 50 and 61 db, with a mean of 55db. This mean value is 5db below the value that characterizes a residential urban community(39), which is the baseline category for the data in the figure. From these results, it appears that no community reaction to an intruding noise is expected on the average, when the normalized Ldn of an identifiable intruding noise is approximately 5db less than the Ldn in the absence of the identifiable intruding noise. This conclusion is not surprising it simply suggests that people tend to judge the magnitude of an intrusion with reference to the noise environment in the absence of the intruding noise source.

The data in Figure 4 indicates that widespread complaints may be expected when the normalized value of the outdoor Ldn of the intruding noise exceeds that existing without the intruding noise by approximately 5db, and vigorous community reaction may be expected when the excess approaches 20db. The standard deviation of these data is 3.3 db above their mean, and ±5db envelopes approximately 90% of the cases. When the data are not normalized, the correlation becomes much less, with the standard deviation increasing from 3.3 db to 7.9 db.

Clearly, the community reaction is better correlated with the normalized value of the Ldn produced by the intruding noise than with its absolute value. The most significant correction involved in the normalization are the background noise (the Ldn that exists without the intruding noise) and the attitude/experience factor. That these factors should be important in community reaction is neither new nor surprising. Before one complains about a noise, one must perceive its existence; and the traditional signal-to-noise ratio is an improtant criterion of detectability. Second, having perceived the noise, one's immediate reactions are often conditioned by one's previous experience and attitudes toward the noise and its source.

On the other hand, it is widely held that some absolute measure characterizing the noise environment must be directly related to interference with speech communication and other activities involving listening, and the physiological effects including hearing damage. This point of view has been substantiated recently by the correlations between the absolute value of Ldn and several important human effects$^{(40)}$.

This latter result does not negate the value of appraising expected community reaction in terms of normalized Ldn. Rather, it implies that both the absolute value and the normalized value of the Ldn should be considered in assessing community noise, particularly in the establishment of standards and ordinances, and in the determination of a criterion for noise control of a new source, such as a factory or highway. The absolute value should be compared to a criterion value based on activity interference and other human effects$^{(40)}$. The normalized value should be compared to data such as those given in Figure 4 to estimate the expected community reaction on an intruding noise. This latter value generally will take priority in establishing a criterion when the Ldn existing in the community before the introduction of an intruding source is lower than the criterion value selected on the basis of activity interference.

In summary, the Leq. which was found to be useful descriptor in analyzing the magnitude of the outdoor noise environment, accounting for all the sounds, regardless of duration, also is useful as the principal component of normalized Ldn, which correlates well with community reaction. These results offer considerable simplification in the long term monitoring of community noise since only one quantity meeds to be measured for many purposes. In this study the Leq. was used to assess the community noise level in this locality (see Appendix I).

* * * * * *

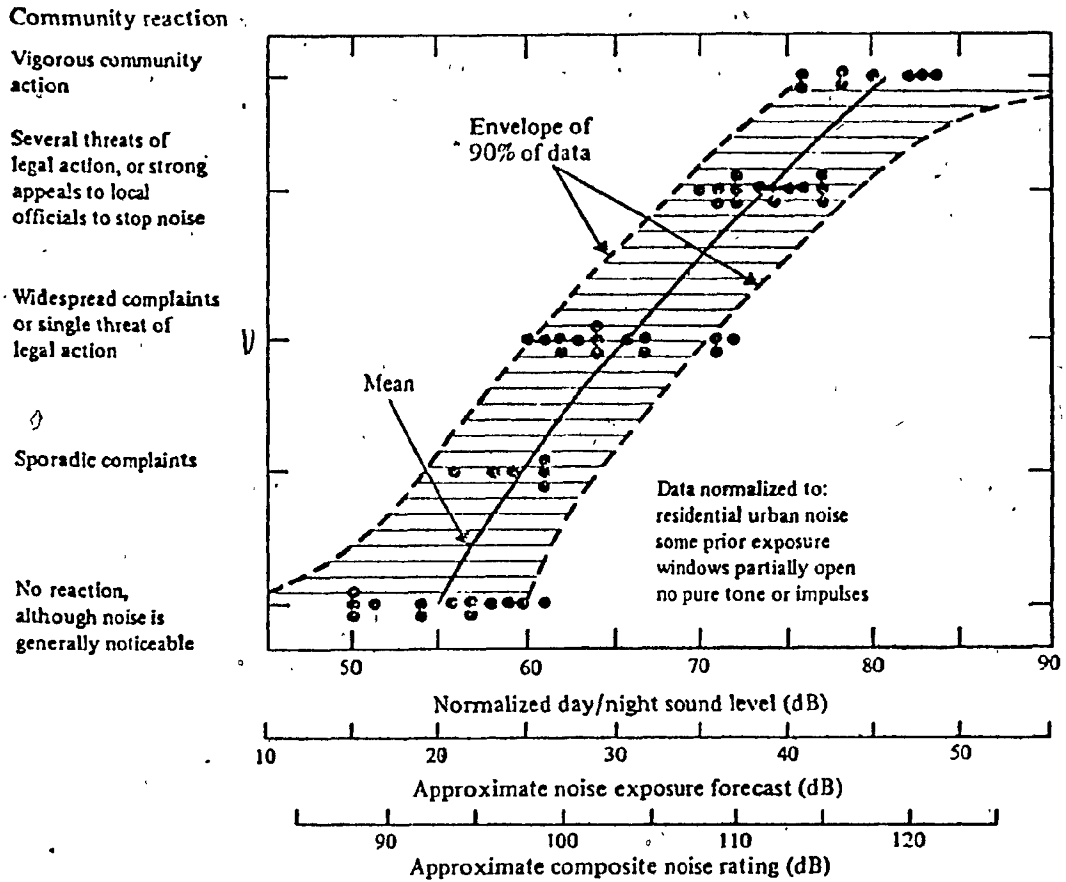


Fig. 4: Community reaction to many types of intensive noise. (From Malcolm J. Crocker, Noise and Vibration Control CRC Press 1975).

CHAPTER 3

BACKGROUND, ORGANIZATIONAL STRUCTURE
AND
CONTENTS OF NOISE REGULATIONS

3.1 HISTORICAL DEVELOPMENT:

Since the days of the early Romans(41), when chariot racing at night was prohibited, and ever since Queen Elizabeth I of England enacted a decree forbidding English husbands from beating their wives after 10 o'clock in the evening so that their neighbours would not be inconvenienced by the cries of the victims, man has, from time to time, introduced regulations to control community noise. This response to the old adage "there ought to be a law against it" was slow in the evolution of community noise laws. However, with the development of our modern industrial machines, many citizens have voiced their objections to the rising environmental noise pollution encroaching upon their lives.

Within recent decades, the noise in our environment has considerably increased to the point that the legislature is taking steps to introduce legal means to limit and regulate the noise levels.

One of the powerful tools to use when the noise has to be kept within given limits are the standards, adopted by various organizations, but unfortunately there are situations where two different standards can be applied. On the otherhand, it is a general belief that more noise standards are needed and that more effort should be devoted to their coordination.

Noise control standards(42) could be classified as a 'performance' code rather than a 'specification' code. The objective of the provision, which in this instance is safety oriented(42), are clearly reflected in terms of expectations of the performance of the built product, and are stated without reference to the specific methods and materials of construction the builder is to use.

In recent years, performance standards in zoning codes, which specify maximum allowable noise limits at certain and fixed locations, have been introduced to strengthen noise ordinaces. Also, some laws now place allowable noise emission levels on transportation vehicles, construction equipment, and other major sources of noise in the community.

In a broader sense, the standards(43) applicable to noise in buildings can be classified into several groups related to

1. Typical noise sources in buildings which are either a functional part of the building or could be independently owned and operated by the building users.
2. Propagation of noise within the buildings.
3. Noise reduction by building structure or by other noise reduction elements applied on various noise sources.
4. Recommended maximum allowable noise levels in various kinds of buildings or under various circumstances.
5. Noise at building sites related primarily to transportation and industrial noise.

3.2 ACOUSTICS STANDARDS OF INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO):

On the international platform, the acoustical standards are created by the Technical Committee 43(44) - Acoustics of International Organization for Standardization (ISO). The purpose of this organization is to adopt standards of broad concept which would be used by national standards organizations as a frame to write more detailed standards modified for the particular national needs. Although much effort is spent to cover the rapidly increasing need for standards, it has to be recognized that the negotiations are very complex and are affected by both the diversity of national interests and the incomplete knowledge of the acoustical laws and relations so that, very often, a lot of research has to be performed before a standard can be completed.

The work of the ISO is concentrated in a subcommittee and working groups. Standards related directly to buildings are written by subcommittee 2 - Building Acoustics. So far, ISO-TC-43 has written 20 recommendations. The following recommendations are related to noise in buildings.(45)

1. R140 Field and Laboratory Measurements of Airborne and Impact Sound Transmission (1960)

This is a fundamental standard related to sound isolation properties of buildings. The recommendation defines field and laboratory methods of measurement of the airborne sound insulation of walls and the airborne and impact sound insulation of floors. It describes the way of generation of the sound fields and impact noise, the requirements on the measuring rooms and it specifies the basic instrumentation characteristics and the frequency range of measurements.

This recommendation has been adopted by the majority of European countries as national standards, sometimes only with minor modifications.

The standard is now 13 years old and is under revision, in particular, the impact noise measurement section is being extended.

2. R354 Measurement of Absorption Coefficient in a Reverberation Room (1963)

This recommendation describes how to measure (for random incidence of sound waves) the absorption coefficient of a material and is based on measurement of reverberation time of a reverberation chamber with and without the materials under test.

The major goal of this recommendation is to obtain comparable data on absorption properties of materials.

3. R717 Rating of Sound Insulation for Dwellings (1968)

This recommendation is related to the values of transmission loss as obtained by the method described in ISO Recommendation R140. It defines a reference value of sound transmission with which the measured results should be compared with a method described. This procedure results in a single index for description or requirements on the sound isolation properties of the portions.

4. R1996 Assessment of Noise with Respect to Community Noise (1971)

This recommendation deals with methods for measuring and ratings of noises in residential, industrial and traffic areas with respect to their interference with rest, working efficiency, social activities and tranquility.

The intention of this recommendation is to provide guidelines to the measurement and ratings of acceptability of noise in communities. After the noise is measured, corrections for duration, spectrum character and peak factor are applied to the measured levels. The corrected values are compared with the noise criterion which takes into account various environmental factors.

The ISO subcommittee 2 - Building Acoustics - is currently working on the following recommendations:

1. Laboratory tests on noise emission by appliances and equipment in water supply installations.
2. Field and laboratory measurements of airborne sound insulation of façade elements and façades.
3. Laboratory measurements of the effectiveness of floor coverings in reducing impact noise transmission.

COMMUNITY NOISE REGULATIONS IN CANADA:

Noise control regulations, although gaining recognition, are not new phenomenon in Canada. In 1965 the parliament had given authority to control noise over most major modes of transportation: air, rail and maritime. According to the Aeronautics Act (46), the Minister of Transport was empowered to make regulations to govern airflight. Concerning landing, take-off angle and hours of flying regulations are made on an adhoc basis for each airport. Canada's position with respect to the sonic boom was altered in 1972. With prior permission of the Minister of Transport now it is possible to create a sonic boom. Also, it is the responsibility of the Federal Government to zone land around airports to uses compatible with airflights. If property values are lowered due to airport construction, it is possible for the residents of that area to sue the Federal Government for compensation.

So far there are no regulations designed to control noise of railway. However, Canadian Transport Commission(47) has power to impose speed limits on trains in urban areas, since noise disturbance from trains usually comes from operation in and near the years of built-up areas and from high speed trains. At present, the Federal Government is not empowered to control noise emissions of motor boats over navigated waters.

Under the Motor Vehicle Safety Act,(47) regulations were established for snowmobiles. Under these regulations snowmobiles manufactured after February 1, 1972 are to emit no more than 82db A at fifty feet. By 1974, the permissible level dropped to 73db A (48). A further regulation under the Motor Vehicle Safety Act(49) limits new automobiles and light trucks to 86db A at fifty feet and trucks and busses to 88db A at fifty feet. However, cars with legal mufflers seldom measure above 80db A even at high speeds. One must observe that in the absence of provincial regulations requiring proper maintenance of cars, motorcycles, buses and snowmobiles, enforcement is difficult.

Under the Canada Labour Code(49), the Federal Government has responsibility for occupational hearing protection(50) "in respect of employment upon or in connection with the operation of any federal work, undertaking or business other than a work, undertaking or business of a local or private nature". Ships, aircrafts, trains and crown corporations are exempted. The regulations set forth the standard for an eight-hour day at 90db A (51). Noise exposure may increase to 114db A as a maximum if the exposure time is limited to fifteen minutes. Under section 3(3), if the limitation of noise is not expedient in the opinion of regional safety officer, an alternative is wearing ear protectors. The above standards are subject to waiver if an employee in an environment of 90dbA to 95dbA is tested regularly and there is affirmative proof that he will not suffer hearing impairment. In addition, section 5 states that no employer shall permit any employee to be exposed to impulsive or impact sound the peak sound pressure level of which exceeds 140dbA unless that employee is wearing ear protectors. The weakness of the regulation is that, while requiring in section 8(1) that survey records be kept for five years, no scheme for testing the hearing of employees at regular intervals is made mandatory. It is up to the safety officer, an appointee of the Minister, to order a survey of the sound level, or an individual hearing test "where, in the opinion of the safety officer, an employee at a work site is exposed to sound levels that may impair his hearing". From this it is imperativ without regular testing and with lax standards, the Federal attempt at regulations can hardly be called a hearing conservation program.

In Quebec, the Minister of the Environment has the duty "to supervise and control noise". In pursuit of this duty, according to section 94 of the Environment Quality Act,(52) he may construct, erect, install and operate any system or equipment necessary in any municipality, and "every municipality wishing to install in its own territory any apparatus or equipment for measuring, detecting, controlling and supervising noise, must previously obtain the authorization of the Minister". The section speaks of an affirmative duty although as yet the Minister responsible has not acted. With the powers conferred by legislature, the Minister would be permitted to order monitoring of noise sources perhaps through a mobile laboratory that could measure the intensity in the various frequencies, the ambient level, and the peak levels of noise within a municipality in Quebec. Apart from the role of the Minister, the Lieutenant-Governor in Council may, according to section 95, make regulations to:

1. Prohibit or limit abusive or useless noise inside or outside a building;
2. determine the terms and conditions of use of any vehicle, engine, piece of machinery, instrument or equipment generating noise;
3. prescribe standards for noise intensity.

Section B could be used to control noise created by the construction industry that makes use of such noisy processes as revetting, pile driving and demolition. The regulations may also limit abusive or useless noise inside and outside buildings, potentially through provincially regulated construction standards. The section speaks of noise intensity regulations but these regulations need not contain one single standard. Consideration of hour of the day, frequency, peak and ambient noise level could also be part of the projected standards. Since there are no regulations, it is suggested that section 20 could provide the legal framework for suits by the government. It reads:

> (20). No one may emit, deposit, issue or discharge or allow the emission, deposit, issuance or discharge into the environment of a contaminant in a greater quantity or concentration than that provided for by regulation of the Lieutenant-Governor in Council.
>
> The same prohibition applies to the emission, deposit, issuance or discharge of any contaminant the presence of which in the environment is prohibited by regulation of the Lieutenant-Governor in Council or is likely to affect the life, health, safety, welfare or comfort of human beings, or to cause damage or to otherwise impair the quality of the soil, vegetation, wildlife or property.

Since sound is a contaminant by definition in section 1(5) where it is likely that it will alter the environment in anyway, all that need be shown is that it affects the "comfort of human beings", a standard that would extricate the court from weighing the harm against the economic necessity of the source. Contravention of section 20 renders the party liable to a fine not exceeding five thousand dollars for the first offence and a fine not exceeding ten thousand dollars for any succeeding offences.

Quebec has shown more initiative in pursuit of regulations concerning snowmobiles. In January 1973, it became law,(53) by section 28, that no snowmobile manufactured after January 1, 1972 shall produce a sound intensity in excess of 82dbA. Mufflers must contain baffles or other equivalent noise-reducing material and are considered in section 81 as safety devices that must be "maintained in good working order" whether built before 1972 or after. In addition, it is prohibited to travel in a snowmobile within one hundred feet of a dwelling, exception being your own land or with permission of the owner.

Under the Transportation Act,(54) use of sounding devices are restricted by modes of construction, use, safekeeping, upkeep, ownership, or possession of any means of transport. The fines under this Act are high, beginning at five hundred dollars. The metro of Montreal and all things used as a conveyance from one place to another are subject to regulation under this Act(55), either with a steam whistle or bell weighing at least thirty pounds.

3.3 NATIONAL BUILDING CODE OF CANADA

Through the National Building Code, Federal influence on noise perceived from within a building could be pervasive. Many, perhaps most, municipalities adopt this code without substantial change. The Code has no legal effect in its Federal form except when enacted in a provincial statute or municipal by-law. It also has an important impact through the Central Mortgage and Housing Corporation which often uses the Code for building standards in housing projects it finances. Provisions in the National Building Code controlling noise are few. There is no regulation of solid-borne sound through pipes and walls, and no internal zoning on specific sound control requirements for party rooms. Also, there are no transmission loss standards for external walls and windows to protect against traffic noise. What it does have is a stipulation that in apartment buildings, walls between suites must have a sound transmission loss of 45dbA, and ceilings must be hung so as to cut impact noise from the floor above. The code could also regulate noise standards for housing sites. If tall buildings are closely located, noise becomes tunnelled, reverberates and has no space to be neutralized. It has been estimated that sound so trapped has increased in intensity five db due to reverberation.(55)

3.4 NOISE CONTROL IN RESIDENTIAL STANDARDS OF CANADA

Residential Standards of Canada (1975) NRCC No. 13991(6) in Section II includes Noise Control. This code provides the requirements for sound transmission class ratings for construction in accordance with ASTM, E 90-70, "Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions".

Also this code provides the following requirement for sound control locations (airborne sound).

All construction shall provide a Sound Transmission class rating of not less than 45 between dwelling units and any space common to two or more dwelling units.

Again it stipulates that every service room or space such as a storage room, laundry workshop or building maintenance room or garage serving more than one dwelling unit shall be seperated from the dwelling units by a construction providing a Sound Transmission class rating not less than 45.

Mainly the above regulations suggest performance standards for party walls in multi-family dwellings. However, there is no performance standards suggested in residential dwellers against traffic noise or other city noises.

3.5 MODEL MUNICIPAL NOISE CONTROL BY-LAW OF ONTARIO:

In 1971, the Ontario Ministry of the Environment enacted a bill stating sound and vibration are also contaminants under the Environmental Protection Act(56). In the same year the Ministry of the Environment initiated studies of environmental noise and noise control. It is generally conceded that the federal, provincial and municipal governments would each have a role to play in an effective noise control program.

It is evident that many of the common sounds and vibrations giving rise to noise complaints were of a local community nature and could be effectively controlled at the municipal level. In October 1975, the Ministry of Environment developed a model noise control by-law with adequate permissive legislative authority to all municipalities in Ontario under the Environmental Protection Act, with a view that the by-law meet the requirements of municipalities of all sizes, provide comprehensive control for most known sound and vibration problems, and provide a unifying base for noise control across the province.

In order to incorporate technological advances, revisions of the model municipal noise control by-law were intended to be prepared from time to time.

A summary of the furnished model municipal noise control by-law is provided for reference.(52)

"1. The by-law will permit a municipal council to exercise broad environmental noise control at the local level under the powers granted by the Environmental Protection Amendment Act, 1974 (No.2).

2. Proper enforcement of a municipal noise control by-law will require the appointment of a noise control officer whose duties may include the following:

   (i) Conduct investigations of noise complaints, including the monitoring of sound levels.

   (ii) Publicize noise abatment.

   (iii) Develop administrative procedures to provide effective enforcement of the by-law.

   (iv) Provide council with such advice as it requires.

3. The by-law may:

   (i) prohibit sounds from squeaking tires, faulty mufflers,

(ii) Limit some noisy activities in sensitive areas to certain times of the day, for instance the operation of auditory signalling devices and loudspeakers, shouting, animal noises, loading and delivery, construction, discharge of fire arms.

(iii) Limit sound levels from certain sources such as, air conditioners, lawn mowers, or motorized conveyances according to specific sound emission standards.

(iv) Specify maximum noise levels for stationary sources on the basis of the equivalent sound level (Leq.) received at a residence.

4. The by-law may permit council to exempt certain traditional activities and provide for other special circumstances.

Enforcement of a quantitative noise by-law is complicated. The accurate measurement of sound is a complex problem particularly when attempting to satisfy legal requirements. In order to successfuly prosecute in court a case based on a quantitative noise control by-law, it is essential that the instrumentation and the measurement procedures used, rigorously conform to the requirements of the Noise Pollution Control Publications published by the Ministry of the Environment. It must be conclusively demonstrated to the court that the measurements given in evidence are accurate, reliable and within the tolerances specified. The publications represent some of the most advanced procedures and instrumentation standards in the field of acoustics. These are set out in a logical and relatively simple fashion. Faithful observance of all of the provisions of the publications will help to convince the court of the validity of the evidence."

The Minister is prepared to assist all municipalities in the adoption and implementation of the by-law, or parts thereof, and particularly, to assist with the technical training of personnel in sound and vibration measurement and enforcement procedures.

The above amendments permit the councils of local municipalities, that is, cities, towns, villages and townships, to pass noise control by-laws, subjected to the approval of the Minister of the Environment.

These by-laws will be updated by a number of supporting publications like:

.Assembly and Approval of By-laws
.Technical Definitions
.Certificate
.Procedures
.Instrumentation
.Construction Equipment
.Residential Air-conditioners
.Domestic Outdoor Power Tools
.Blasting
.Sound Level Adjustments
.Guidelines on the Duties of a Noise Control Officer
.Estimating Sound Levels from Ground Transportation
.Guidelines for Noise Control in Land-use Planning

3.6 MUNICIPAL NOISE CONTROLBY-LAW OF MONTREAL (88)

In Montreal, the Director of the Social Affairs Department has the responsibility of implementing part 2 of By-law 4996 concerning noise, which is going into effect this spring.

Currently, this department is involved in preparing a noise contour survey of the Montreal region, which is expected to be completed within a year. From the data collected to date, it can be inferred that the noise climate in Montreal is similar to other North American cities. The contour noise level is being measured in L_{95} which differs slightly from the conventional L_{90} used elsewhere in North America.

In order to satisfy legal requirements, the by-law specifies the instrumentation requirements and recommends the method of measurements and normalization. The following maximum normalized levels are suggested for acoustic comfort in a dwelling:

Bedroom < 30 dbA
Livingroom < 40 dbA
and other areas < 45 dbA

For offices < 50 dbA; hospitals < 45dbA; and parks < 60 dbA; for the protection of customer, the inside noise level of a discotheque should not be more than 98 db.

To date, the by-law 4996, concerning noise, is basically a noise nuisance law. If there is any complaint and if the peace officer, who is authorized to look after the noise complaint is convinced there is excessive noise, in view of the time, may order whoever is the cause of that disturbance to put an immediate stop to it. Whoever shall not comply immediately with the order shall by guilty of a violation and be liable for a first violation, to a maximum fine of one hundred (100) dollars, with or without costs, for a second violation of the same provision of this bylaw within a twelve (12) month period, to a fine of at least one hundred (100) dollars and at the most, five hundred (500) dollars with or without costs. Any subsequent violation within the same period, to a fine of at least five hundred (500) dollars and at the most one thousand (1000) dollars and to imprisonment for sixty (60) days at the most should he fail to pay the fine within ninety (90) days.

EVOLUTION OF COMMUNTIY NOISE REGULATIONS IN THE U.S.A.

There is long legislative history to the control of enforcement of noise in the U.S.A. This history has continued unbroken to the present day. Local control of municipal noise in the United States has involved four stages of evolution.

Stage One: Pre-1930

The city of Boston (57) was the first to regulate noise, beginning in 1850. This ordinance was primarily concerned with noise occuring in the public place that would disturb the peace. Consequently, restrictions were placed on the use of public spaces for generating noise related activities. It was not until the beginning of this century that cities as a group became interested in regulating noise.

Initial interest was expressed by larger cities. Here the emphasis was on public spaces and street related functions since this was an era before zoning and land use regulations. Despite these earliest attempts few strides were made in municipal noise control. Less than twenty American cities adopted noise laws. These laws dealt with noise in court for legal interpretation.

Stage Two: 1930-1947

During the 1920's recognition of urban problems began. The first Noise Abatement commission in the U.S.A. was established by the Mayor of New York(57). It sought to identify city noise sources, assess their impact, and recommended solutions. Their report City Noise, published in 1930(57), was unique in many ways. An acoustical inventory of noise was undertaken along with a survey of public opinion. It is interesting to note the typical sources of noise considered offensive to New Yorkers at that time are remarkably similar to those identified today. This widely circulated report recommended laws for controlling noise which were to be adopted by many other cities.

Primary noise provision included muffler requirements' for vehicles building construction restriction in residential areas, prohibiting horns and whistles, regulation of peddlers, and vendors, and prohibiting noise from mechanical or electrical sound making or reproducing equipment.

Although inroads were made in broadening the legal language regulating noise and techniques for assessing it, there were still several inadequacies. Noise was still defined in nuisance terms. Municipal programs remained few in number, and those enacted were not consistently enforced.

Stage Three: 1948-1969

During this stage some of those inadequacies were at least partially overcome. The National Institute of Municipal Law

Officers (NIMLO) prepared a research report giving guidance to municipalities in controlling noise(58). This report which was subsequently referred to as the NIMLO model ordinance was to be widely disseminated and adopted. The Environmental Protection Agency reported in 1971 that nearly 35% of those cities surveyed had adopted this model, while others had incorporated certain sections or provisions(59). This model also has had limitations since it did not contain quantitative provisions. It was not until 1952 that specific noise emission levels appeared.

These first laws contained vehicle noise level requirements expressed in decibels. Seattle, followed by Cincinnati, adopted these first quantitative ordinaces(59, 60). Following the control of mobile noise sources were laws establishing specific fixed source limits, which used the zoning ordinance as the legal basis. Chicago, Illinois, in 1955, adopted the first law restricting noise related land use activity(61). It represented a new approach to zoning.

Although major breakthroughs to those did occur during this formulative period more obstacles were facing cities who wanted to establish effective noise control programs. It was during the end of this period that the United States having larger resources, and learning from the experiences of local government, slowly became active. California was the first to address the problem of vehicular noise in an effective manner, by amending the motor vehicle code (62).

Cities in certain States began to relinquish their power to regulate motor vehicle noise. Nevertheless municipal governments were now in the process of adopting legal provisions that were enforceable. Few, if any, comprehensive noise programs were in existence however, and the mechanism for administration and enforcement still was weak.

Stage Four: 1970 to Present

Cities in three States during the beginning of Stage Four enacted programs that were to overcome pervious deficiencies in administration and enforcement. Boulder, Colorado; Inglewood, California, and Chicago, Illinois all made notable strides in controlling municipal noise during 1970-71(63,64). In 1971 Chicago adopted a fully revised ordinance which has generated national attention.

Several model type ordinances are now appearing to provide more professional guidance to communities desiring assistance. NIMLO modified their earlier nuisance type ordinance, adding decibel provisions as an alternative in 1970(65). Within the state of California the League of California Cities prepared a model document. It contains several provisions, including sound levels for zoning districts in rural, suburban and urban areas(66).

Significant state-wide acitivity is now occuring that is or will influence municipal programs. There are now seventeen states that have types of noise law concerened with zoning and land use, motor vehicles, aircraft, and building codes(67).

Activities by several key cities and states are having a profound impact on the rapid number of new municipal programs. To date there are over 400 cities with ordinance representing a combined pupulation of nearly 70 million people(68).

3.8 DEVELOPMENT OF NOISE CONTROL STANDARDS IN THE U.S.A.:

The ISO standards, discussed earlier are modified for particular federal needs in the U.S.A. and many other countries. In the U.S.A. building codes, usually in conjunction with land-use prescriptions, offer one avenue for protecting dwellers from excessive noise. The codes are indeed the only avenue left to a municipality to control noise where superior government, as in the United States and the United Kingdom, has pre-empted jurisdiction over aircraft and other kinds of noise.

The codes that include provisions for the regulation of noise are two principal types: performance codes and material codes. Performance codes prescribe a certain performance in the reduction of noise for the particular structure or machine being regulated. They can prescribe performance, either on the basis of results of laboratory tests of the performance structure. Laboratory test performance presents less of an unknown to a builder than field test performance, because the latter may lead to expensive modification if, after construction, the final performance is not satisfactory. Material codes specify in detail the type of materials to be used in particular kinds of construction, on the assumption that the compliance with the code will lead to the desired performance.

Each type of code has advantages and disadvantages. Performance codes are more difficult to enforce, but if enforced give a better guarantee of noise reduction. They are usually feasible only if there is an adequate staff to enforce them - for example, in the larger cities. Material codes reduce the burden on the enforcement officials who may not be able to monitor performance; yet they tend to discourage innovation in the use of materials and therefore need periodic updating. The city of Irvin, Texas for example has a material code.

3.9 MULTI-FAMILY DWELLING CODES:

The development of these codes has been surprisingly slow: in the United States in 1972 there were only two codes for multi-family dwellings dealing with internal noise (69) - the San Fransisco code and the New York code. Both are performance codes. In the San Fransisco code performance is assessed primarily on the basis of field tests, while in the New York code it is assessed primarily through laboratory tests.

3.10 NOISE PROVISIONS OF CERTAIN BUILDING CODES IN THE U.S.A.:

The New York City code which went into effect December 6, 1969 is quite comprehensive and some of its major provisions are listed below.

The New York City code applies only to multi-family dwellings. Compliance with the code is established after the building is constructed and is ready for occupancy. Although not specifically stated in the code, after construction has been completed the builder or contractor is required to have an independent firm conduct measurements to determine whether or not the structure conforms to the code. If the New York City Department of Buildings is not satisfied with the results or the manner in which the tests were conducted, it may conduct its own test before issuing the necessary permit to allow occupancy.(70)

The foregoing may be the intent on the law, but the code merely states:

> FIELD TESTING: Where conditions indicate that the installed construction or equipment does not meet the noise control prescribed in this article, measurements shall be taken to determine conformance or non-conformance. For conformance with this article, the results of such measurements shall not fail by more than 2 db SPL, to meet the requirements in any octave band, or by more than two points to meet any STC or INR requirements.(70)

Thus it appears that if for some reason a multi-family dwelling, was not inspected prior to occupancy, the code could be applied on a complaint or called-for-basis.

The code provides a list of National Standards which are to be consulted whenever conducting tests. Laboratory tests are to be conducted in accordance with American Society for Testing and Materials Standards, ASTM E-90-70. Field tests are to follow E336-67T.

The code provides requirements (STC, IIC) for interior walls, partitions, floor/ceiling constructions, and mechanical equipment spaces to provide protection for each dwelling unit from extraneous noise emanating from other dwelling units and mechanical equipment. The code also has provisions to regulate airborne sound from exterior mechanical equipment.

For airborne noise, walls, partitions, and floor-ceiling constructions seperating dwelling units from each other or from public halls, corridors, or stairs have a minimum STC rating of 45. For permits issued after January 1, 1972, the STC required shall be 50. After January 1, 1972 dwelling unit entrance doors shall have a minimum STC of 35. For structure-borne noise, "... floor-ceiling constructions shall have a minimum Impact Insulation Class IIC of Zero".

3.11 CALIFORNIA NOISE INSULATION STANDARDS(71):

Under California Noise Insulation Standards which went into effect August 22, 1974 a new discipline has been added, that of acoustical engineering. Compliance with state Noise Insulation Standards is now required for all new multi-family dwelling units constructed in California. These standards set minimum ratings for the sound transmission of party walls and floor/ceiling seperations between dwelling units. In addition, a maximum allowable interior noise level is specified from external sources such as noise from traffic on arterials, rail system movements, and industrial activities, aircraft flyovers.

The California Standard considers two areas of noise control of multi-family dwelling units. These are:

1. Insulation of Separating Wall and Floors, and
2. Isolation of Interior Spaces from Exterior

Isolation means the materials or constructions (or the use of such materials or constructions) which resist the passage of sound through them.

Here, one must note that a noise nuisance might be abated by the introduction into the factory or a building of sound absorbent materials thereby decreasing the volume of noise capable of being transmitted. However, it should be borne in mind that the reduction of sound by absorption (that is, the reduction of reverberant sound) can never be greater than 10 dbA, and is often much less.(72) Therefore, although absorption can be useful, it is no real substitute for insulation. If a room is bare, as many workshops are, an acoustically absorbent ceiling may reduce the overall sound pressure level by 5 - 10 dbA but a brick wall will reduce transmission by 40 - 45 dbA.(72)

There must be no confusion between absorption and insulation. Absorption of sound by a material means that the sound is not being reflected from the surface of the material. The reverberation is reduced.

Insulation refers to the sound transmission loss. Generally speaking, any material which will readily absorb sound pressure waves will also readily transmit them. Any material or surface which reflects sound pressure waves will also be a good insulating material.

No single material will act both as an efficient absorbent and a good insulator. Covering the surface of a party wall with acoustic tiles or foam rubber will make no difference to the transmission loss in the wall.

To cover the insulation requirement the state adopted the 1973 uniform building code requirements for sound transmission control. ASTM procedures of testing party wall and floor/ceiling assemblies are accepted. The most common test, the room-to-room test, according to the ASTM procedure requires at least a volume of 1500 cu.ft. For most dwelling spaces, this corresponds to a minimum floor area of about 200 sq. ft.

3.12 FLANKING PATHS:

When a test is required to demonstrate compliance with the California Standard, "all sound transmission from the source room to the receiver room shall be considered to be transmitted through the test partition". When field tested, however, flanking paths contributed significantly to the noise measured between the spaces in question and the completed structure did not comply with the standards. Hence California Noise Insulation Standards stipulate a STC value of 45 for walls if field tested and 50 for laboratory tests.

3.13 IMPACT SOUND CONTROL:

In addition to specifying the minimum STC of walls, the Standard specified a minimum Impact Insulation Class (IIC) for floor/ceiling assemblies. The Standard states that "floor coverings may be included in the assembly to obtain the required ITC rating...". Most carpeted floor assemblies comply with the impact provisions of the standard. Uncarpeted floor requires a resilient underlayer, such as a cushion backed vinyl to meet IIC of 50 (45 if field tested) imposed by the Standard.

3.14 EXTERIOR NOISE ISOLATION:

The standard specifies that the Interior Community Noise Equivalent Level attributable to exterior sources shall not exceed 45 dbA in any habitable room. The CNEL measure is A-weighted average of hourly sound levels. It is determined by placing a penalty on evening and night-time sound levels and averaging these on an energy basis along with the daytime noise, to achieve a 24-hour average sound level. Annual CNEL is a 365-day average of the daily CNEL.

In addition to specifying an allowable interior CNEL, the Standard states that "residential structures to be located within an annual CNEL contour of 60 require an acoustical analysis showing that the structure has been designed to limit introducing noise to the prescribed allowable (interior) levels".

It is important to note that exterior noise limits are not set by the standard, community noise equivalent levels are identified by local jurisdictions during the preparation of their general plan, as required by California State Law.

Location is proximity to major airports, primary highways and freeways, and the main-line railways may be exposed to excessive noise, and, therefore, will require analysis and design considerations. In general, residential units should not be located in areas where the CNEL is greater than 65 dbA. Barriers should be located between the noise source and the residential property to reduce CNEL to at least 65 dbA.

Following is a summary of Noise Insulation Standards of the California Administrative code:

1. Wall and floor/ceiling assemblies - separating dwelling units shall meet a Sound Transmission Class (STC) of 50 (45, if field tested), and an Impact Insulation Class (IIC) of 50 (45, if field tested).
2. Entrance doors from interior corridors shall have a STC rating of not less than 30.
3. Laboratory tests of wall and floor/ceiling designs having an STC and/or IIC of 50, may be used to establish an acceptable design.
4. Field testing of proposed walls and floor/ceiling systems to obtain STC and/or IIC ratings, if required to prove compliance with the code, shall include all flanking paths.

3.15 NOISE INSULATION FROM EXTERIOR SOURCES:

Residential location having a CNEL greater than 60 dbA require an acoustical analysis showing that the structure has been designed to meet the interior CNEL of 45 dbA.

CNEL shall be determined by local jurisdictions as part of its general plan (noise element). Exception - railroads with only four day time and night time operations.

Evidence of the above compliance with the standards is to consist of "an acoustical analysis".... "to be submitted with the application for a building permit."

This report must provide at least:

1) Topographical relationship of noise source (highways, railroads, airports, etc.) and the location of the building unit;
2) Exterior noise spectra for both present and future noise sources of concern;
3) Analysis to show the effectiveness of the proposed construction to reduce interior noise adequately; and
4) A ventilation analysis and design must be provided to indicate that a habitable interior environment will be provided, if the interior allowable noise level is to be met with windows closed.

3.16 SUMMARY:

A survey of acoustical codes and standards is presented within which a) ISO acoustical standards; b) Residential Standards of Canada; c) Model Municipal Noise Control By-law of Ontario; d) Municipal Noise Control By-law of Montreal; e) New York City Noise Code; and f) California's Noise Insulation Standards are discussed.

It could be seen among all the standards discussed that California's Noise Insulation Standards are the most comprehensive standards existing to this date; as an example, these standards set a maximum allowable interior noise level from external sources; hence this standard is taken as the model for the investigation of the cost consequences to implement improved noise control standards in the region of Quebec.

* * * * * *

CHAPTER 4

THE EFFECT OF WINDOW WALL COMBINATIONS

4.1 GENERAL

This section discusses the characteristics of window wall combinations. Several hypothesis about the character of these requirements can be advanced, all of which have cost implications.

Before going into the actual discussions of this section, it is proposed to explain some of the terms used herewith for a better understanding.

4.2 FREQUENCY SPECTRUM AND OCTAVE BAND ANALYSIS

The practical use of frequency bands in describing a noise source is exemplified by Figure 5 which shows the one-third octave band level for an executive jet aircraft at an altitude of 500 feet during an approach operation. Sound-pressure levels from a series of contiguous bands can be contained by procedures such as those in Figure 6 to yield an overall sound-pressure level for the entire frequency range. The basic consideration in building up the overall level is the non-linearity of the superposition of sound when measured in decibels. Thus, two sources of 70 dB yield 73 dB; this level combined with a 75 dB yields 77.1 dB, etc.

4.3 MEASUREMENT OF SOUND

Overall sound levels are measured by a sound level meter which, in its simplest form, comprises a transducer, amplifier and a readout device (Figure 7). The signal indicated by the meter is proportional to the sound level at the microphone, so that the meter scale can be calibrated in decibels referred to a standard pressure of 0.0002 dynes/cm^2.

$$\text{Sound pressure level (dB)} = 10 \log p^2/p_o^2 = 20 \log \frac{p}{p_o}$$

$$= 20 \log \frac{p}{0.0002}$$

Measurements obtained by such a meter are purely objective, but can show marked departure from sound loudness interpretation because of the differing effects of different frequencies on subjective rating. To compensate for this, 'weighting' must be applied to control the response versus frequency characteristics. It follows from the contours of equal loudness - Figure 8 - that a very large number of weighting networks would be necessary to ensure correct weighting for any level of noise. To avoid such practical complication (and cost) for industrial applications, weighting is normally confined to three networks corresponding to the contours for 40, 70 and 100 dB, known as A, B and C weightings, respectively. Readings taken under such conditions are then correctly referred to as weighted sound levels rather than sound pressure levels.

In general, A weightings are most suitable for measuring low sound levels (under 55 dB) B weighting for medium sound levels (55-85 dB). A and B weightings have a response which decreases with decreasing frequency, whilst C weighting gives a substantially flat response over a frequency range of 25 HZ to 8000 HZ - Figure 9.

It is obvious from the diagram that the greatest difference between the different weightings will occur at low frequencies. Thus in the range of frequencies up to 1000 HZ (and virtually all overall sound measurements will include these frequencies) it is essential to specify which rating applies, eg. dB(A), dB(B) or dB(C).

In practice, dB(A) is most commonly applied (and preferred) for measurement of specific categories of noise over the whole range of sound levels involved, this rating being selected as being the closest of the three to subjective response; that is subjective evaluation of loudness. C weighting is generally used where the sound level meter supplies a signal to an auxiliary instrument for analysis.

4.4 RELATION BETWEEN STC AND A-WEIGHTED CURVE

A strict test procedure is prescribed in ASTM E(74) 90-70 for the Sound Transmission loss of panels and walls. Figure 10 shows the sound transmission loss varying with frequency for a panel measured in 1/3 octave band intervals. It is common practice (75) to replace this curve by a single number rating and call it the Sound Transmission Class (STC). This is accomplished by adjusting vertically the STC criterion curve (shown in Figure 10) until the average of all data points below the criterion curve is no more than 2 dB below the criterion curve. When so adjusted, the Sound Transmission loss at 500 Hz is taken off the criterion curve as the STC value. For the example shown in Figure 10, the STC value equals 26.

In this work all the composite structures are rated in STC, a single number rating. The STC ratings are normally used with intention to overcome certain inadequacies developed when the sound attenuating quality of a space divider was expressed as the numerical average of its TL at but a few frequencies.

The requred insulation for the compound structures is obtained by the equation (73):

$$STC = CNEL - N_A$$

where STC = Noise reduction characteristics expressed as an STC number

CNEL = Community noise equivalent level (it is a measure using A-weighted sound level)

and N_A = Interior acceptable noise level characteristics expressed in an A level

In this equation, CNEL and N_A are A-weighted, single number sound levels, the STC is also a single number rating but not A-weighted. To justify using this equation, the following phenomenon is considered(76).

It is generally accepted that noise level grading curves such as A-weighted level curves are used to establish a simple relationship between a definite existing noise level characteristic and the required noise reduction of the boundaries of an enclosure in which it is desired to establish a certain maximum noise level spectrum termed A-45.

This characteristic is the inverse of a 'A' network in the common sound level meter, and is so labelled, say A-45, because the 'A' weighted sound level of the noise level characteristic will come to this value, that is, 45 dBA. All 'A' noise level spectra are alike in shape, and differ only in their ordinate position on the common graph paper as used in Figure 10. Also similar in shape STC curves, which likewise differ only in their position on the same graph paper. On Figure 10, for instance, is shown STC-26. It could be noticed in the figure that the 'A'-network also closely resembles the STC curve.

It could be idealized from the above example that when the 'A' noise level A-45 is graphically added to the STC-50 spectrum, one would obtain the maximum noise level characteristic which may prevail outside the dwelling's boundary to establish these in the recommended A-45 noise level characteristics.

Thus when the A-weighted noise level of the dwelling's exterior is 90 dBA, and has a shape similar to that shown in Figure 10, and the desired maximum acoustic disturbance is A-45, we have

$$\begin{aligned} STC &= 95 - 45 \\ &= STC\ 50 \end{aligned}$$

The simplification of the calculation results from the fact that the STC characteristic closely resembles the 'A' network, which is displayed in Figure 10.

Figure 11 was obtained considering 45 dBA to 105 dBA as the Community Noise Equivalent Level which covers all the possible outside noise levels from a farm in the valley to an urban residential area near a major airport(76,77). An attempt was made to assess the Community Noise Level in the location of the Centre for Building Studies, Concordia University, and was found to be 73 dBA.

From Figure 11 the required average transmission of external envelope could be determined in any CNEL ranging from 45 dBA to 105 dBA to have a desirable Internal Noise Level of 45 dBA as stipulated by California's Noise Insulation Standard.

From the discussion of Chapter III, it could be seen that the performance approach is generally regarded as a more progressive way of describing components than is the specification language approach. In the development of such codes, performance statements are usually first developed in broad descriptive terms (eg., the party walls shall have a minimum Sound Transmission Class (STC) rating of 45). These statements are then potentially in a form suitable for codification. Thus, it is necessary that the generalized performance requirements be translatable into appropriate physical characteristics which can, by suitable testing or prediction techniques, be measured. In making this translation, the measurable attribute may or may not end up closely reflecting the spirit of the original requirement. Its attraction lies in its familiarity and extensive back up data, in addition to test procedures. The STC values are commonly used to describe the TL of panels, walls, windows and doors.

Sound Transmission through walls (or floors and ceilings) varies with frequency of the sound and the weight (or mass) and stiffness of the construction.

By definition, the Sound Transmission Loss (STL) of a partition(75) is given by:

$$STL = 10 \log \left(\frac{I_i}{I_t}\right), \text{ dB}$$

in which I_i = sound intensity on one surface of the partition in watts per square meter.

I_t = sound intensity radiated from the opposite surface of the partition in watts per square meter.

The intensity of I_t is less than I_i, since some of the incident energy is reflected back toward the source, while another portion is absorbed by the material of the partition.

The Sound Transmission loss is determined experimentally for a partition between two reverberation rooms by the following expression:

$$STL = L_1 - L_2 + 10 \log (s/a)$$

in which L_1 = time space average sound pressure level in the source room.

L_2 = time space average sound pressure level in the receiving room.

s = the total radiation surface area of the partition in square meters.

a = total sound absorption in the receiving room in Sabins.

The difference $(L_1 - L_2)$ is called the noise reduction of the partition.

If the partition is a rigid barrier with air on either side, it can be shown that the Sound Transmission loss is described by what is called the field incidence mass law:

$$STL = 20 \log wf - 47.4$$

in which w = area density of the barrier in kilogram per square meter.

f = frequency of the sound in Hertz.

For example, a brick wall 0.3048m thick has an area density equal to 590 kg/m^2. If the frequency of the incident sound is 500 Hz, then:

$$STL = 20 \log (590)(500) - 47.4$$
$$= 109.4 - 47.4 = 62.0 \text{ dB}$$

In a building, in general, the insulation provided by the external walls is appreciably greater than that attainable with windows. Thus, in almost every case, the determining factor is the size of windows and the character of glazing, as the TL of a non-homogeneous wall is largely governed by the TL of its weakest component. To show to what extent a large closed window can weaken the composite Transmission Loss of an otherwise highly sound-retardant construction, consider a large brick wall whose masonry components have a TL of 45 dB, has 20 percent of its space taken up by single glazed windows whose TL equals 20 dB, the TL of the composite wall will be 22 dB. In a dwelling, the TL of the walls is usually controlled by area occupied by doors and windows.

Thus the solution to the problem of how to avoid sound transmission through highly sound-retardant walls containing a window or windows, doors etc. consists in minimizing the window area and maximizing the TL of the window. Since the Residential Standard of

Canada stipulates, for lighting purposes, a window area equal to 10 percent of area served, the minimum window area is fixed, and no reduced sound transmission can be had by a smaller window. With respect to increasing the TL of the window itself, essentially two means are possible - thicker sheets of glass in a single-pane window, or double-pane windows. The first means is not very practical, since doubling the thickenss of a homogeneous panel results in only a 4.5 dB increase in the transmission loss for all frequencies (78), but the double-pane windows are more commonly used to increase TL and have an additional advantage due to their improved thermal properties. The use of sealed double-glazing units has expanded greatly in recent years. As they may represent a major item in the cost of the building enclosure, and as they have certain potential limitations as well as advantages, an awareness of their physical characteristics is essential for our further discussion.

There are, in general, three types of construction used for hermatically sealed glazing units (78):

Type I - in which a spacer of lead is bonded to the glass by a special soldering technique;

Type II - which has an all-glass edge;

Type III - in which the panes are sealed by one or more organic sealants to an aluminium, steel of polyvinyl chloride spacer, usually hollow and containing a desiccant.

The air in the space is dried by purging with dry air before sealing in Types I and II, and by contact with the desiccant in Type III. The majority of sealants are polysulphide, butyl or other synthetic rubber base materials, with various additivies to provide the desired properties. Type I and III units usually have 1/2 or 1/4 inch air spaces; although a few Type III units are made with 5/8 inch spaces. Type II usually has 3/16 inch air spaces. The effectiveness of a window is directly related to the overall airtightness of the installation. This is the reason why fixed windows are better for sound control than openable windows.

The STC value, in case of double windows, increases as the space between the panes is increased. For a relatively high degree of sound control (an STC of over 40) it is necessary to provide two panes of glass separated by at least an 8 inch space, not a very practical situation in most cases. There is a fundamental difference in this regard between heat and noise control. Typical over-all heat transmission coefficients versus thickness for glass-enclosed air spaces are shown in Figure 12. The optimum thickness for minimum heat flow is about 5/8 inch; thickness of 1/4 and 3/16 inch are significantly less effective. Figure 13 displays the average sound transmission loss of single and double-panel windows versus thickness for glass-enclosed air space. The TL increases with the thickness of glass, increasing with the air space. For thermal insulation there is little advantage in an air space larger than 3/4 inch.

The portion of the study dealing with the cost consequences associated with technical contents of Noise Control regulations is divided into the following phases:

- Determining the required average sound insulation to have a desirable internal noise level of 45 dBA for any given outside Noise Level.
- Determining composite transmission loss when single, double and triple glazed windows of 10 to 100 percent opening fitted into walls of different STC values.
- Cost of composite wall/sq.ft. for the given extenal noise level.

The objective was to obtain a family of curves describing cost implications associated with varying window openings for different STC value of walls. Included are studies which yield cost information of intrinsic usefulness for designers and builders interested in controlling housing costs while implementing Noise Control Standards. Cost curves were developed, for example, for the cost per sq. ft. of enclosures as a function of window area/wall area and outside noise level to obtain a desirable inside noise level. These curves were useful in assessing the cost implications of Noise Control Standards in the design and planning of multi-family dwellings, and are similarly useful in the context of setting minimum standards for window openings in each.

The first phase of this study of determining the average sound insulation to have a desirable internal noise level of 45 dB A for any given outside noise level is discussed in Chapter 5 .

The second phase of study deals with the determination of composite transmission loss when single, double and triple glazed windows of 10 to 100 percent opening are fitted into walls of different STC values. The rest of this chapter discusses the construction of mathematical models to pick up the most economical combination.

Walls are available in various thicknesses; consequently, various TL values (i.e., costs) also windows are available single, double and triple glazed. The problem is often to pick the most economical combination that will achieve a certain required noise reduction.

To accomplish this, initially, knowledge of the TL of composite construction is essential. This is represented by the following equation:

$$\text{TL Composite} = 10 \log \frac{(A_1 + A_2)}{\tau_1 A_1 + \tau_2 A_2}$$

where A_1= net area of wall excluding opening

A_2= area of opening

τ_1= Transmission coefficient of wall

τ_2= Transmission coefficient of window

τ_1 and τ_2 are calculated using the expression:

$$TL_{wall} = 10 \log 1/\tau_1$$

$$TL_{window} = 10 \log 1/\tau_2$$

Using the above expression a computer program was written; and the Composite Transmission or $TL_{composite}$ was obtained for walls having STC value ranging from 30 to 60, fitted with single, double and triple glazed windows of 23, 20 and 43 respectively, and varying the percentage of window opening from 10 to 100 percent.

The family of curves shown in Figure 14 was obtained by considering single glazed sealed window having 23 dB of Transmission Loss (TL) and walls having STC value ranging from 30 to 60 are taken into consideration. In each wall 10 to 100 percent of window openings are assumed and the composite TL of external envelopes are established. The figure displays percentage of single glazed window openings vs Composite Transmission Loss of window and walls. From Figure 11 the required Composite Transmission Loss for a given external noise is obtained. Then, the value of optimum window openings for each STC value of wall could be obtained as follows.

Suppose the required Composite Transmission Loss is 28 dB, entering the ordinate of Figure 14, 28 dB and moving horizontally across the scale to the STC 30 dB wall, and from that point on down to the abscissa, could obtain the figure of 13 percent opening of single glazed sealed window of 23 dB. Similarly, still moving horizontally to the STC 35 wall, could obtain the figure of 29 percent of possible opening of single glazed sealed window in STC 35 wall to have a 28 dB of Composite Transmission Loss. Thus Figure 14 is used to obtain the Composite TL of the composite barrier of different combinations.

Further it could be seen from Figure 14 that it is not possible to fit single glazed sealed windows if the required TL is greater than 35 dB. It could be also noticed that there is no great advantage to have higher STC value walls when single glazed windows are used as the Composite Transmission Loss increases only 32 to 33 dB, by increasing STC value of the wall from 40 to 60 dB.

As a matter of interest, at the location of the Centre for Building Studies the estimated average CNEL is 73 dBA (Appendix I). To have a desirable average inside noise level of 45dBA, at this location from Figure 11, the required Composite TL of the external envelope should be 28 dB. The permutations and combinations for this location are, considering single glazed sealed window of not more than 13 percent openings in an STC 30 wall, no more than 25 percent for STC 35 wall; less than 30 percent for STC 40 wall; and walls ranging from STC values 40 to 60 the possible openings vary from 30 to 100 percent to have a Composite Transmission Loss of 28.

Figure 15 displays a family of curves of double glazed sealed windows having 40 dB TL vs Composite Transmission Loss of window and walls. As before, the walls fo STC value 30 to 60 are considered to achieve a certain required Composite Transmsision Loss if fitted with double glazed window of 10 percent to 100 percent opening in each wall area. Knowing from Figure 11 the required Composite Transmission Loss for a given external noise the value of optimum double glazed window opening for each STC value of wall could be obtained from Figure 14. Further it could be seen that it is not psosible to fit double glazed sealed windows if the Transmission Loss required is greater than 50 dB. It could be noticed also, that there is no great advantage to have higher STC value walls when double glazed windows are used as the Composite Transmission Loss increases only 47.5 to 50 dB, by increasing STC value of wall from 50 to 60 dB.

Similarly Figure 16 displays percentage of triple glazed window openings vs Composite Transmission Loss of window and walls. Figure 11 gives the required Composite Transmission Loss for given external noise; the value of optimum triple glazed window opening for each STC value of wall could be obtained from Figure 16.

A double window will, providing the frequency spectra remains reasonably constant, give the same measured reduction in sound whether the external noise level is a bearable 50 dBA or an excruciating 120 dBA. But there is one variable - window size- that it seems advisable to consider in greater detail. From the enclosed graphs it could be implied that opportunities to observe adjustments to price variations are most likely to occur as a consequence of sound insulation changes, varying with window sizes. Cost could increase proportionally according to increase in wall area glazed. As such the graphs give a broad indication of how window size might effect the performance of improved insulation. Sound proofing costs in general depend on the amount of insulation required, the size of windows, the method adopted, and on geographical and economic variables.

The following recommendations could be made from Figure 14 through 16. Noise reduction depends on various window-wall combinations.

- Single glazed sealed windows should be used only if the required Composite TL is less than 33 dB.
- There is no great advantage of using high STC value walls while using single glazed sealed window, as the composite TL increases on 32 to 33 dB, by increasing STC value of wall from 40 to 60.

- While using double glazed sealed window the maximum attenuation possible is 50 dB (allowing 10 percent minimum glazing).
- It is not economical to have a combination of double glazed window and wall of STC value more than 50 dB since the composite TL increases 47.5 to 50 dB by increasing the STC value of wall from 50 to 60.
- The highest Composite TL could be reached while using triple glazed window which is 53 dB (allowing 10 percent minimun glazing).

The cost implication of window wall combinations will be discussed in the next chapter.

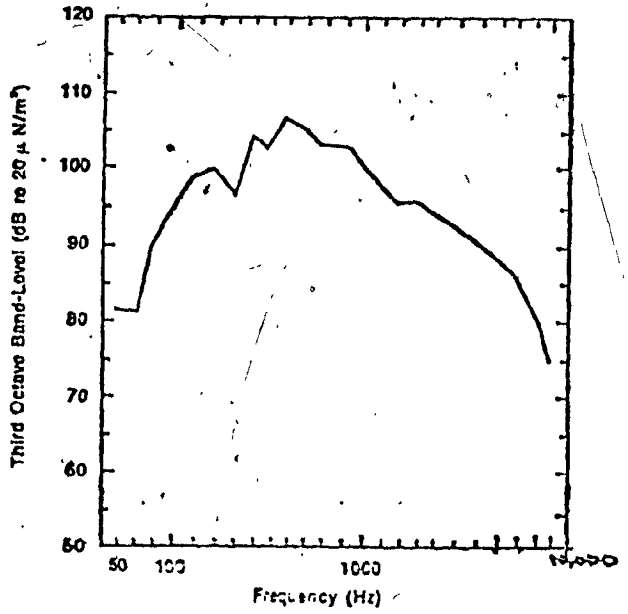


Figure 5: One third octave-band level for executive aircraft of 500 feet during approach operation (Source: EPA Fundamentals of Noise: Washington, 1971 (a))

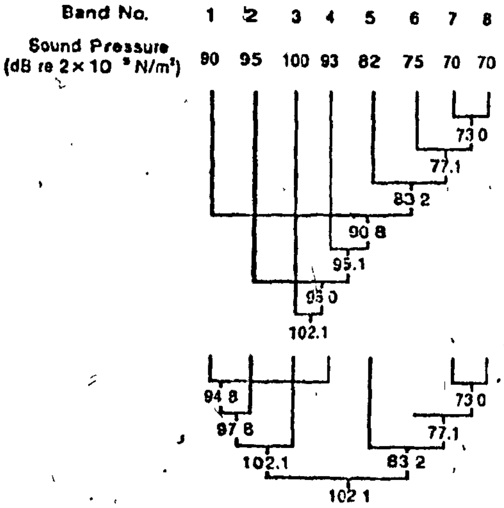


Figure 6: Determination of an overall sound pressure level from levels in frequency bands.

Two methods (Source: Beranek : Noise and Vibration Control, N.Y., McGraw Hill, 1971)

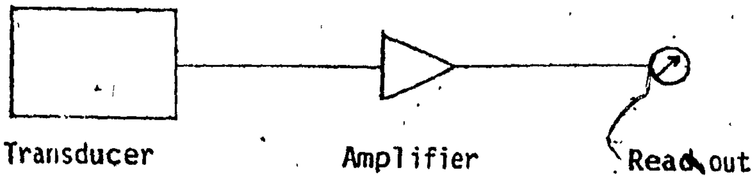


Figure 7: Basic measurement system.

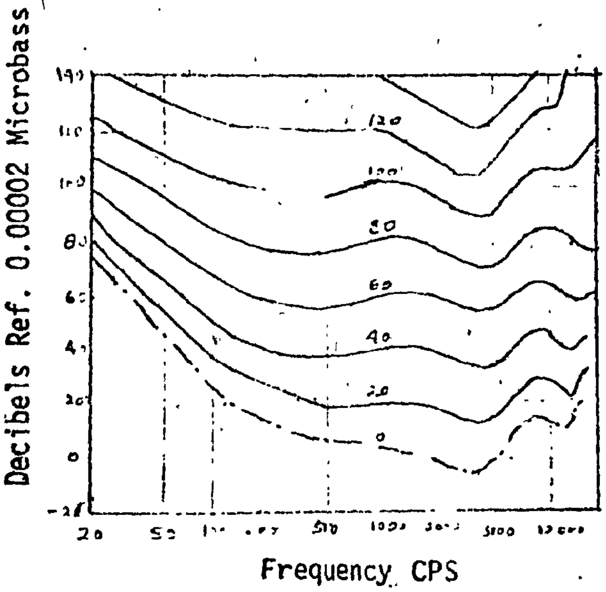


Figure 8: Contours of equal loudness.

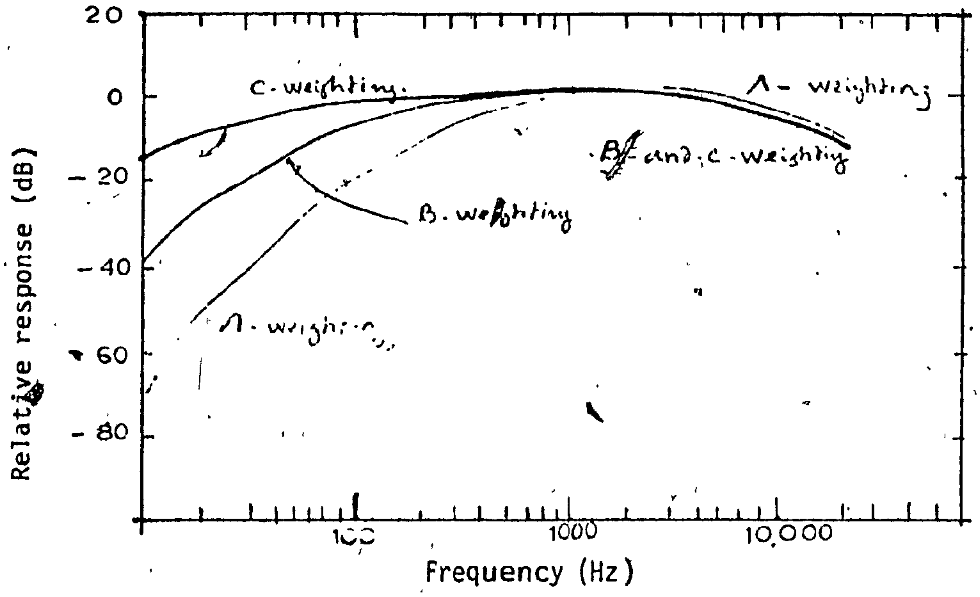


Figure 9: Relative response of the A, B, and C weighting networks (Source: IEC Standard A, B and C weighting curves for sound level meters)

When the TL of windows and walls are known, a knowledge of the commonly used external envelopes enables one to find out the cost of the composite structure.

5.2 DESCRIPTION OF THE TYPES OF WALL USED IN THIS INVESTIGATION

In this study one hundred and fifty types of commonly used exterior envelopes with STC values ranging from 27.5 to 67.5 fitted with 10 to 100 percent single, double and triple glazed windows were analysed. For clarity in presentation of results, the STC rating numbers are approximated to center of a given range. For example:

STC 30 means STC 27.5 to STC 32.5

STC 35 means STC 32.5 to STC 37.5

STC 40 means STC 37.5 to STC 42.5

STC 45 means STC 42.5 to STC 47.5

STC 50 means STC 47.5 to STC 52.5

STC 55 means STC 52.5 to STC 57.5

STC 60 means STC 57.5 to STC 62.5

STC 65 means STC 62.5 to STC 67.5

Figures 17 through 24 show typical walls considered for cost analysis. The unit costs of the wall were calculated (see Table 2) using Building Construction Cost Data 1977(79) for the Montreal region, and the unit cost of sealed windows were obtained from the manufacturers.

As is evident from descriptions of construction shown in Figures 17 to 24, the constructional fabric used is that typcially found in a non-luxury dwelling unit. Estimated costs were determined per unit of component enclosure surface (eg: dollars per square foot of exterior enclosure glazed with 10 to 100 percent of surface area). Thus the total cost of a component is roughly the unit enclosure cost times the component surface area.

Cost data was taken from Building Construction Cost Data(79) for the current year of this region. Traditional information sources were used in the above literature for cost data. Hence estimates were approximate. As noted, only relative cost values are of any direct value and undue significance should not be attached to specific dollar estimates. The latter were used primarily as a convenient tool for establishing relative values.

While calculating the unit cost of walls, it was found that generally 1/3 of cost per unit of wall goes to the materials used and 2/3 of cost goes to the installation, scaffolding and labour. It could be noticed that up to an STC 45 wall the increment in cost was gradual and from STC 45 to STC 55 there is a sudden increment in cost due to more labour involvement, and primarily due to the necessity of double wall construction above STC 45.

5.3 EFFECTS OF COST ON WINDOW OPENING

While the cost of wall for STC 35 to STC 65 is calculated to range from \$2.08 to \$8.60, the cost of single, double and triple glazed windows are \$11.40, \$17.00 and \$25.00 per sq. ft. respectively. Hence the percentage of window opening is the chief cost determing factor in any envelope. The enclosed Figures 25 to 27 were developed from the calculated unit cost of commonly used walls fitted with 10 to 100 percent of single, double and triple glazed windows in each wall. They display percentage of window opening vs. unit cost of composite construction. The cost of composite structure increases with the increase in percentage of window opening. To obtain the approximate cost of the required composite wall the following procedure is used and is demonstrated by use of examples. From Figure 11, for a given Outside Noise Level of 75 dBA, the average Sound Transmission of the composite structure must be 30 dBA to have a desirable inside noise level of 45 dBA. Referring to Figure 14 using single glazed window, the various combinations of wall and window for an average TL of 30 are: an STC 35 wall, 14 percent opening; STC 40 wall, 17 percent opening; STC 45 wall, 18 percent opening; and STC 55 wall, 20 percent opening, and so on. From Figure 25 the corresponding costs varies from $3.50 for an STC 35 wall; $4.00 for an STC 40 wall; $4.50 for an STC 45 wall; to $8.40 for an STC 55 wall. It could be inferred form these examples that there is little advantage in going for higher STC value walls without restricting the glazed area.

If the given outside noise level is 80 dBA to have a desirable internal noise level of 45dBA, the Composite TL must be 35 dB (Figure 14). As the maximum average TL, using single glazed window, has been calculated to be 33 dB, one must use double glazed windows to achieve a Composite TL of 35 dB.

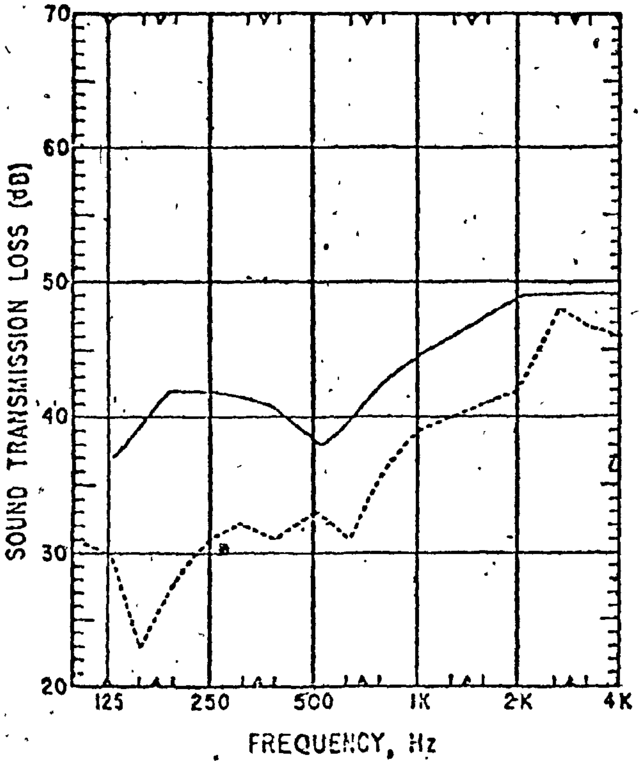
Using double glazed windows, from Figure 15, to accomplish a 35 dB of Composite TL, the glazed area must be 75 percent in an STC 30 wall and 10 percent of glazed area is enough in an STC 35 wall.

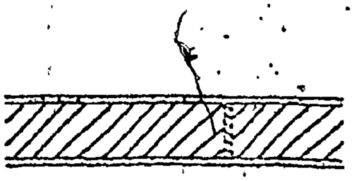
From Figure 26, the cost of double glazed window and wall combinations to achieve a 45 dBA of internal noise level are $13.00 per square foot using an STC 30 wall; $3.50 using an STC 35 wall; $4.40 using an STC 40 wall, and so on. From this example it could be seen using higher STC value walls are economical, if the percentage of window openings, the chief cost determining factor, is kept minimum.

In economical terms, it works out better to provide a wall of STC value slightly higher than the required Composite Transmission Loss fitted with minimum percentage of window opening, the chief cost determining factor. If the cost of the envelope is to be minimized, the glazed area must also be minimized.

Another interesting way of interpreting the Figures 25, 26 and 27 is to note the variation in the percentage of window openings in each STC class of wall while keeping cost constant. Thus for a $5.00 per square foot wall, using single glazed windows, 16 percent opening in an STC 50 wall, 20 percent opening in an STC 45 wall, 22 percent opening in an STC 40 wall, 30 percent opening in an STC 35 wall, 33 percent opening in an STC 30 wall can be utilized. Hence a choice of wall and window opening could be obtained simply by choosing a more optimum configuration for prescribed dollar.

As the external envelopes are chief noise barriers in a multi-family dwelling, only external envelopes are considered in this investigation. The choice however, proved to be the most viable technique for the goal of analyzing cost implications of implementing improved noise control standards. The accuracy of the technique was felt to be fully commensurate with the objectives of this study.





W-14

DESCRIPTION OF CONSTRUCTION

W-14:

TYPE: HOLLOW GYPSUM BLOCK

DESCRIPTION: 4 in. hollow gypsum blocks cemented together with 3/8 in. mortar joints; on each side, 5/8 in. sanded gypsum plaster.

TOTAL THICKNESS: 5 in.

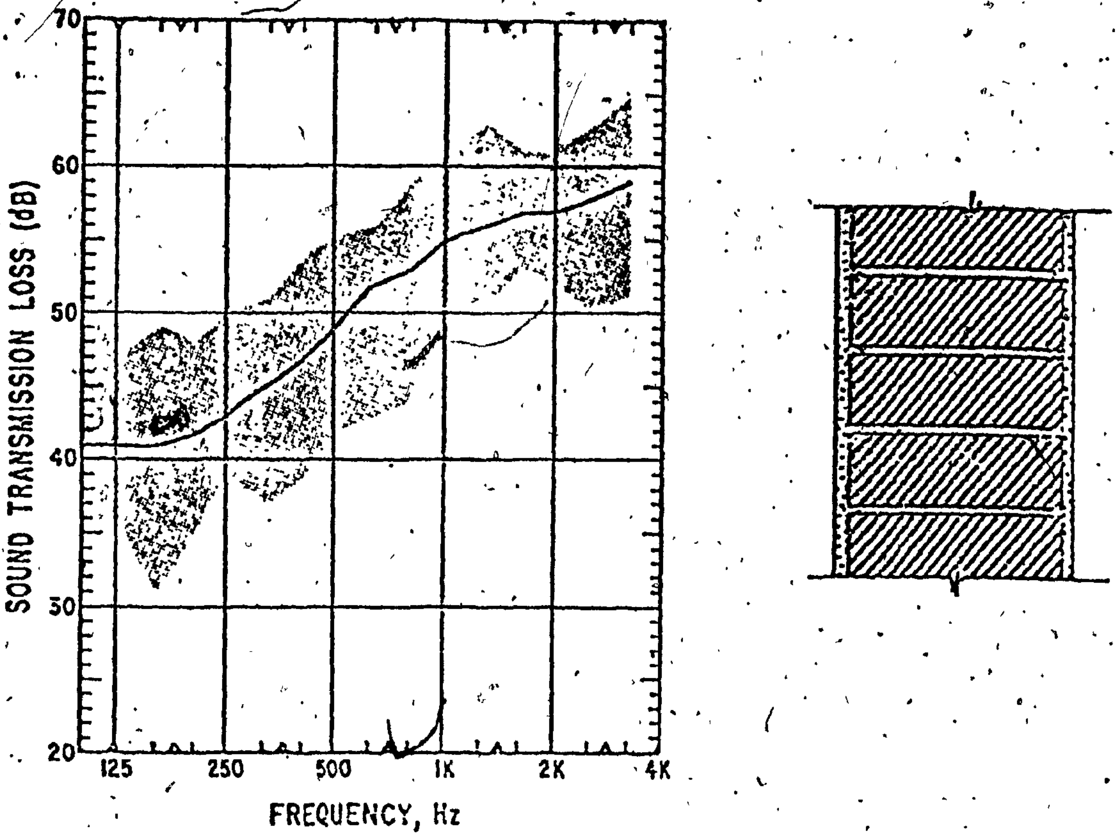
AREA WEIGHT: 23.4 lb/ft.^{2}

FIRE RATING: 4 Hrs.

SOURCE: Noise Control in Multifamily Dwellings, U.S. Department of Housing and Urban Development, Washington, D.C. 20410

ESTIMATED COST FOR SECTION: \$2.08/ft.^{2}

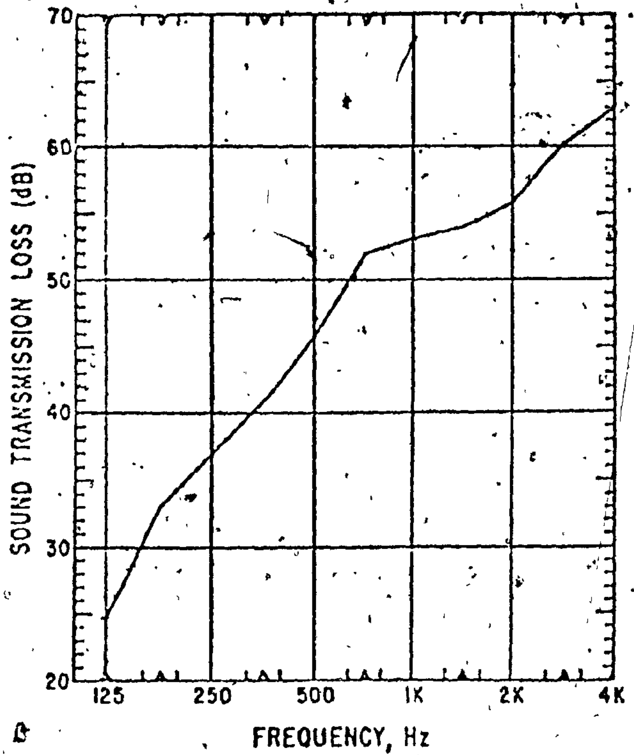
Figure 17

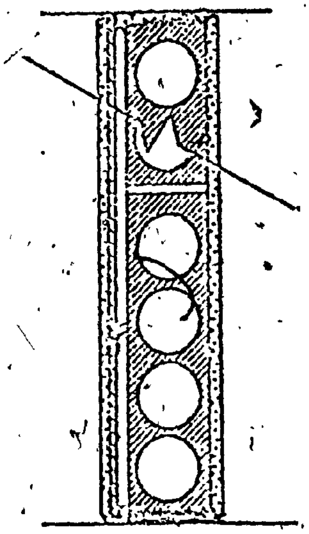


W-6

TYPE:	BRICK
DESCRIPTION:	9-in.-thick brick wall with a ½ in.-thick layer of plaster on each side.
TOTAL THICKNESS:	10 in.
AREA WEIGHT:	100 lb./ft.
STC RATING:	52
FIRE RATING:	over 4 hrs.
SOURCE:	Noise Control in Multifamily Dwellings, U.S. Department of Housing and Urban Development, Washington, D.C., 20410
ESTIMATED COST FOR SECTION:	$3.56

Figure 18



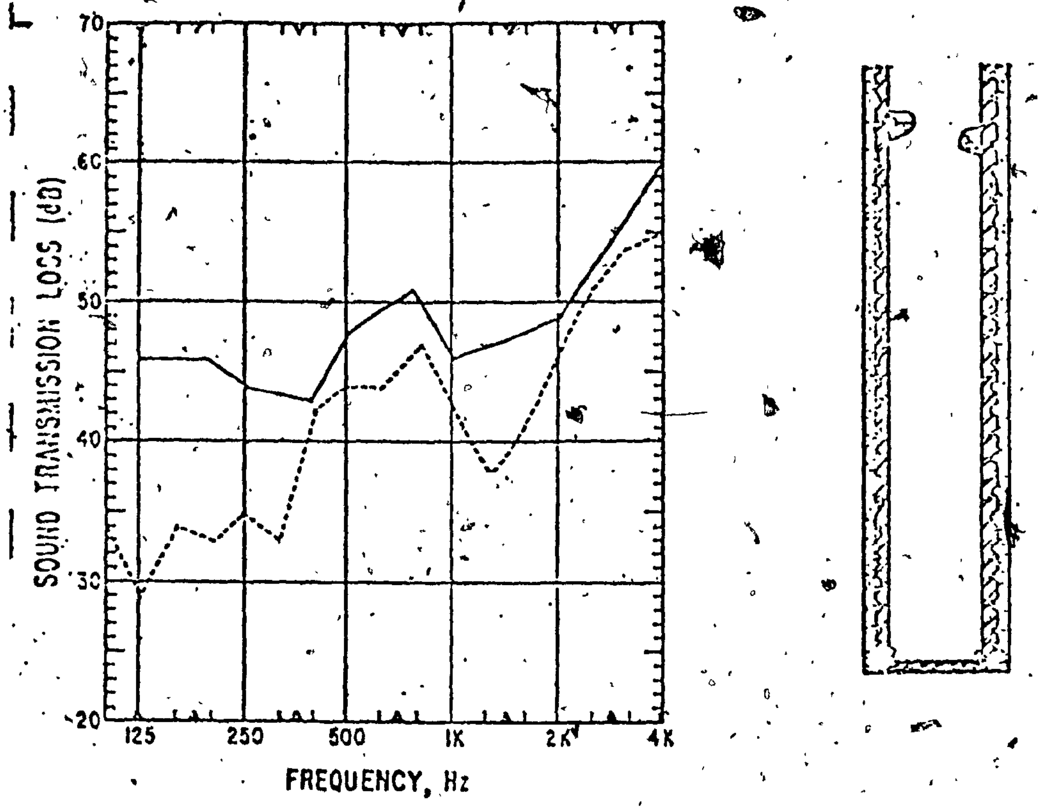


Source: Noise Control in Multi-family Dwellings, U.S. Department of Housing and Urban Development, Washington, D.C. 20410.

W-19

TYPE:	HOLLOW GYPSUM BLOCK, GYPSUM LATH AND RESILIENT CLIPS ONE SIDE.
DESCRIPTION:	4 in. x 12 in. x 30 in. hollow gypsum blocks isolated around perimeter with 1/2 in. thick continuous resilient gaskets on one side, 3/8 in. gypsum lath attached with resilient clips 16 in. on centres, 1/2 in. sanded gypsum plaster with white-coat finish applies to lath; on the other side 5/8 in. sanded gypsum plaster with white-coat finish applied directly to gypsum blocks. The 1/4 in. clearance around the perimenter closed with a non-setting resilient caulking compound.
TOTAL THICKNESS:	6 in.
AREA WEIGHT:	24.1 lb/ft.^{2}
STC RATING:	47
FIRE RATING:	4 hrs.
ESTIMATED COST FOR SECTION:	\$3.37/ft.^{2}

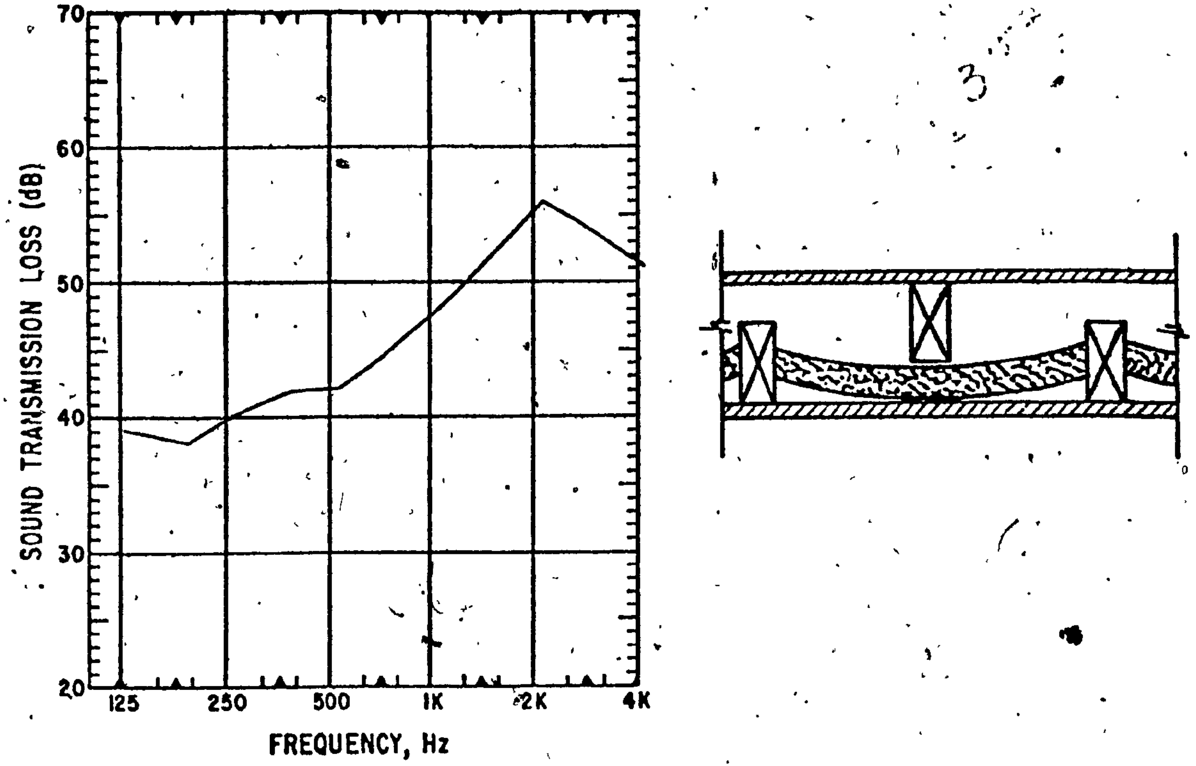
Figure 19



W-73

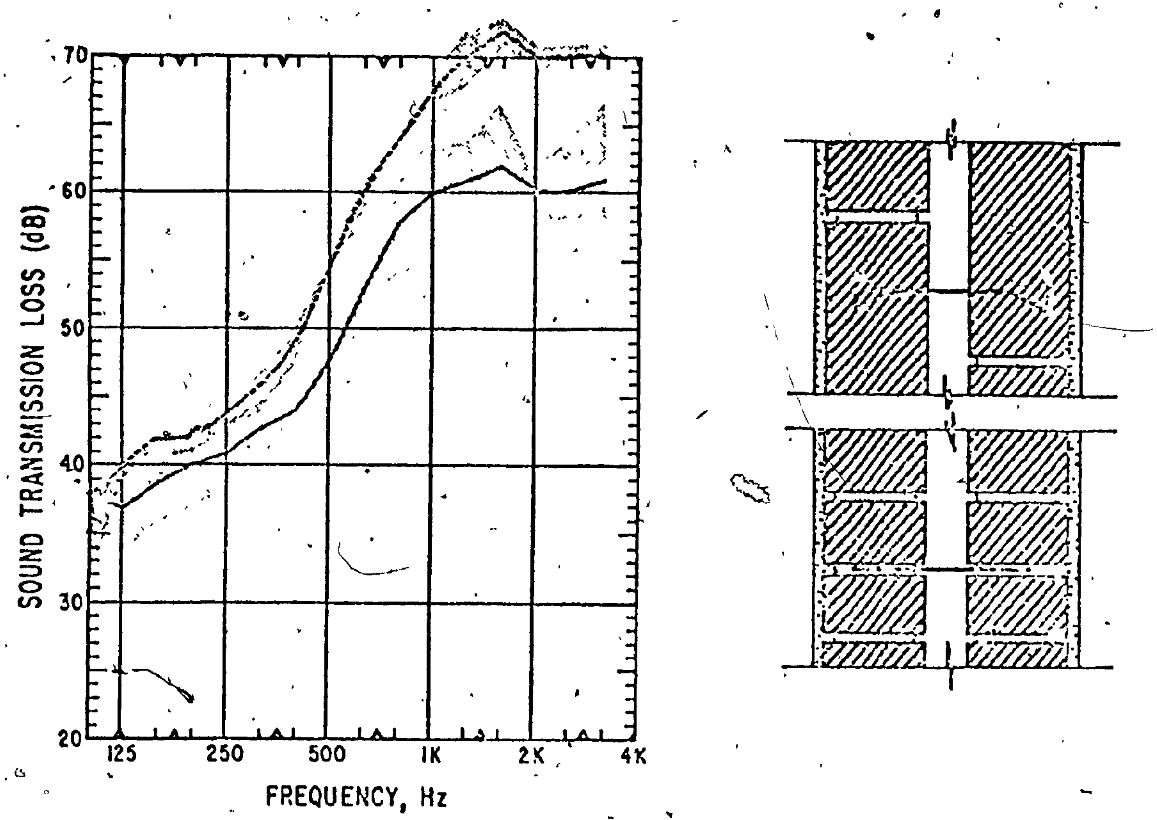
TYPE:	DOUBLE WALL, SOLID PLASTER LEAVES
DESCRIPTION:	Double wall on concrete with a face-to-face separation of 4½ in., each leaf consisted of 3/4 in. metal channel, 12 in. on centres stiffened by a 1 in. horizontal metal channel about half-way up the panel; expanded metal lath and 3/4 in. sanded gypsum plaster on both sides of the wall.
TOTAL THICKNESS:	4½ in.
AREA WEIGHT:	17.2 lb./ft.^{2}
STC RATING:	47
FIRE RATING:	1 hr.
ESTIMATED COST FOR SECTION:	\$3.50/ft.^{2}

Figure 20



TYPE:	STAGGERED WOODEN STUD, GYPSUM BOARD WITH INSULATION
TEST REF:	2-(236)
DESCRIPTION:	2- by 4- in. wooden studs 16 in. on centers, staggered 8 in. on centers, attached to 2- by 4 3/4-in. wooden floor and ceiling plates; 1/2-in. gypsum wallboard nailed on both sides to studs, 0.9-in. wood-fiber wool blanket stapled on the inside of one side of the wall. All joints taped and finished.
TOTAL THICKNESS:	5 3/4 in.
AREA WEIGHT:	13.8 lb/ft^2
REMARKS:	The STC value is based upon nine test frequencies. STC = 46
SOURCE:	Noise Control in Multifamily Dwellings, U.S. Department of Housing and Urban Development, Washington, D.C. 20410.
ESTIMATED COST:	$3.60

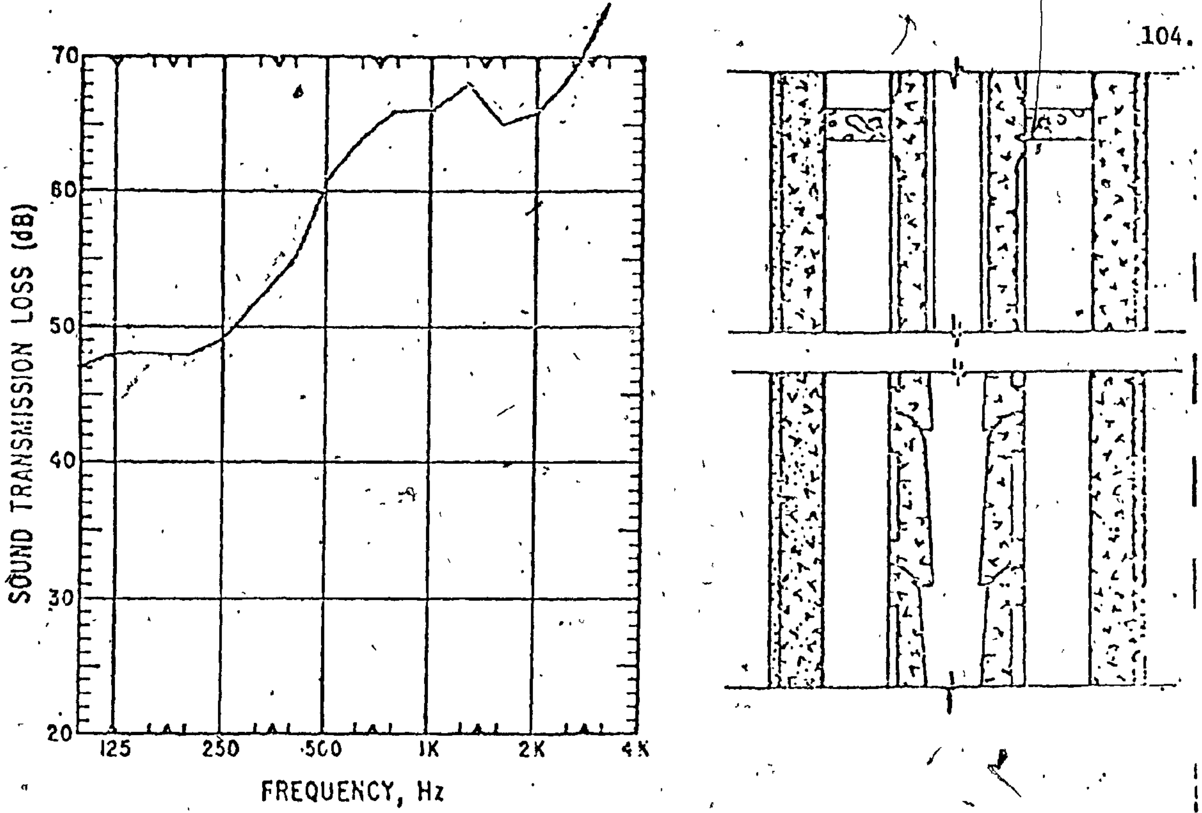
FIGURE 21



~~W-22~~

TYPE:	DOUBLE BRICK WALL - 2 in. cavity
DESCRIPTION:	Double wall with 4½ in.-thick brick leaves separated by a 2 in. cavity; ½ in. plaster on exposed sides.
TOTAL THICKNESS:	12 in.
AREA WEIGHT:	100 lb./ft.^{2}
STC RATING:	54
FIRE RATING:	over 4 hrs.
ESTIMATED COST FOR SECTION:	\$7.50/ft.^{2}

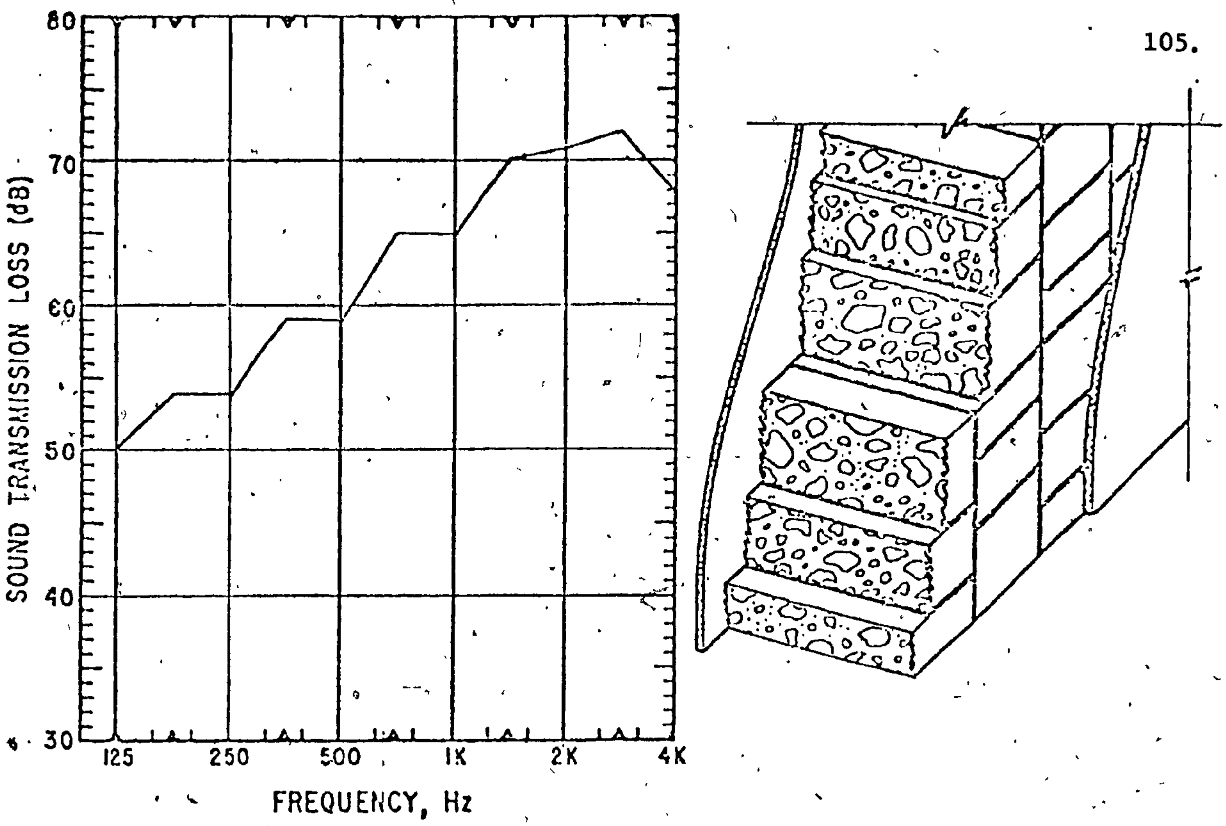
Figure 22



W-26

TYPE:	DOUBLE WALL CONCRETE PANEL AND CLINKER BLOCK
DESCRIPTION:	Double wall consisting of approximately 2 in.-thick concrete panels mounted on 2 in. x 4 in. reinforced concrete posts spaced 18 in. on centers with inner leaves of 2 in.-thcik clinker block; a 2-3 in. cavity between inner leaves; $\frac{1}{2}$ in.-thick plaster coat on the exposed surfaces.
TOTAL THICKNESS:	19 in.
AREA WEIGHT:	80 lb./ft.^{2}
STC RATING:	60
FIRE RATING:	over 2 hrs.
ESTIMATED COST FOR SECTION:	\$8.00/ft.^{2}

Figure 23



W-4

TYPE:	SOLID CONCRETE BLOCK
DESCRIPTION:	Wall of 4-, 6- and 8 in. x 8 in. x 16 in. sand and gravel aggregate solid concrete blocsk; on each side, ¼ in. to ½ in. thick layer of cement gypsum plaster and sand.
TOTAL THICKNESS:	approximately 16 in.
AREA WEIGHT:	184 lb./ft.^{2}
STC RATING:	63
FIRE RATING:	over 4 hrs.
ESTIMATED COST FOR SECTION:	$8.60/ft.^{2}

Figure 24

TABLE 2

BASIC CONSTRUCTION COMPONENTS AND ESTIMATED COST

LOCATION: MONTREAL, QUEBEC

ESTIMATION FOR 9 -in. THICK BRICK WALL

CREW D-3	LABOR RATES CREW D-3 Hr.	Daily
3 bricklayers or stone mason	$8.01	$192.24
2 bricklayer helpers	$6.76	$108.16
0.25 carp (scaffolding)	$7.77	$ 1.94
42 M.H. Daily Total		$302.34

ITEM	COMMON BRICK IN 9-IN. THICK WALL	
1030 brick delivered	$86 per M	$ 88.60
Mortar material @ $1.20/C.F.	17 C.F.	$ 20.40
Scaffold rental		$ 3.85
Installation incl. scaffolding using indicated crew	Crew D-E 0.556 days	$168.10
Total per M in place		$280.95
Total per S.F. of wall	9-in. thick wall	$ 3.56

FOR SINGLE GLAZED WINDOW

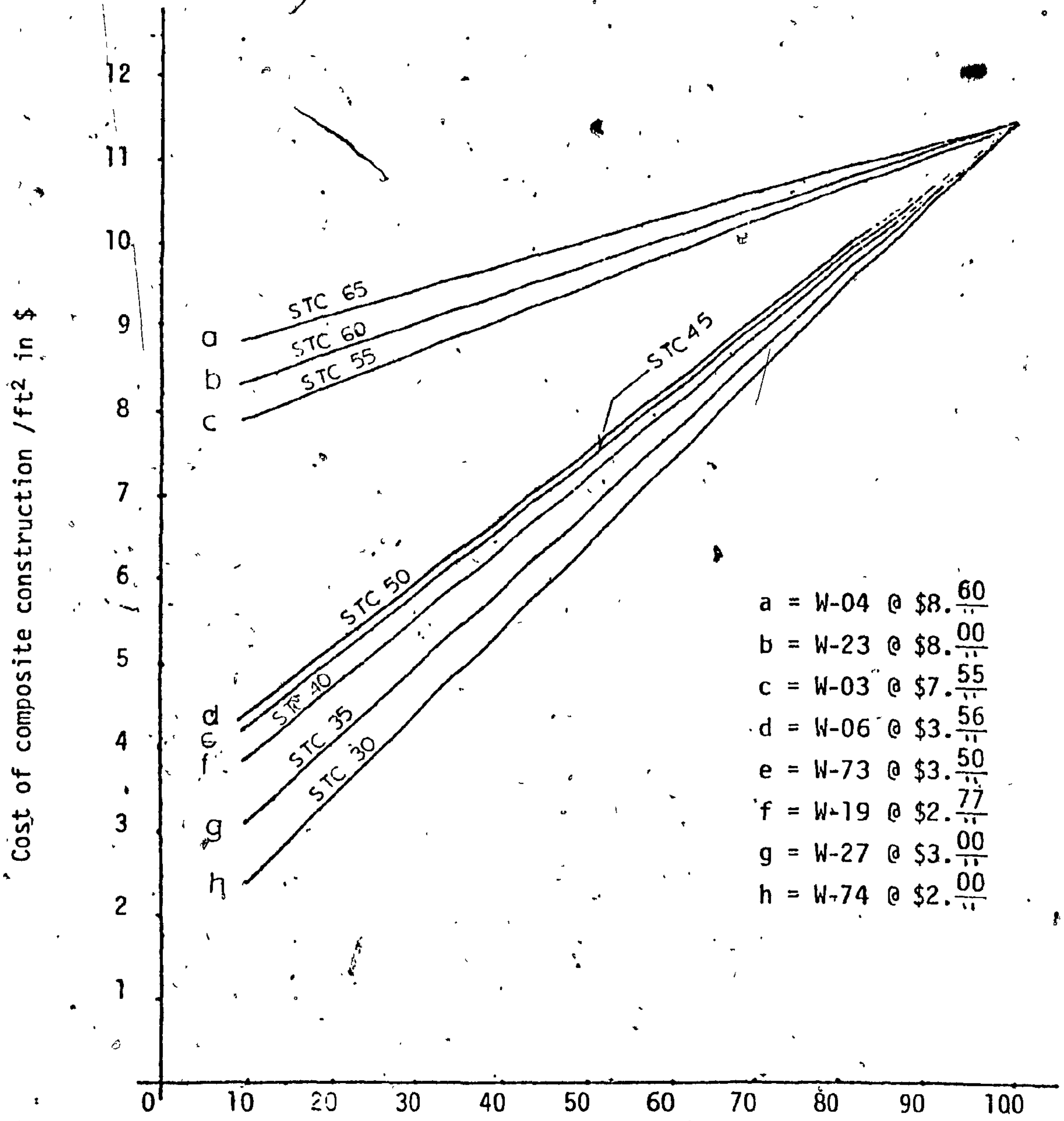


Figure 25: Percentage of window opening @ $11.40/ft.^{2}

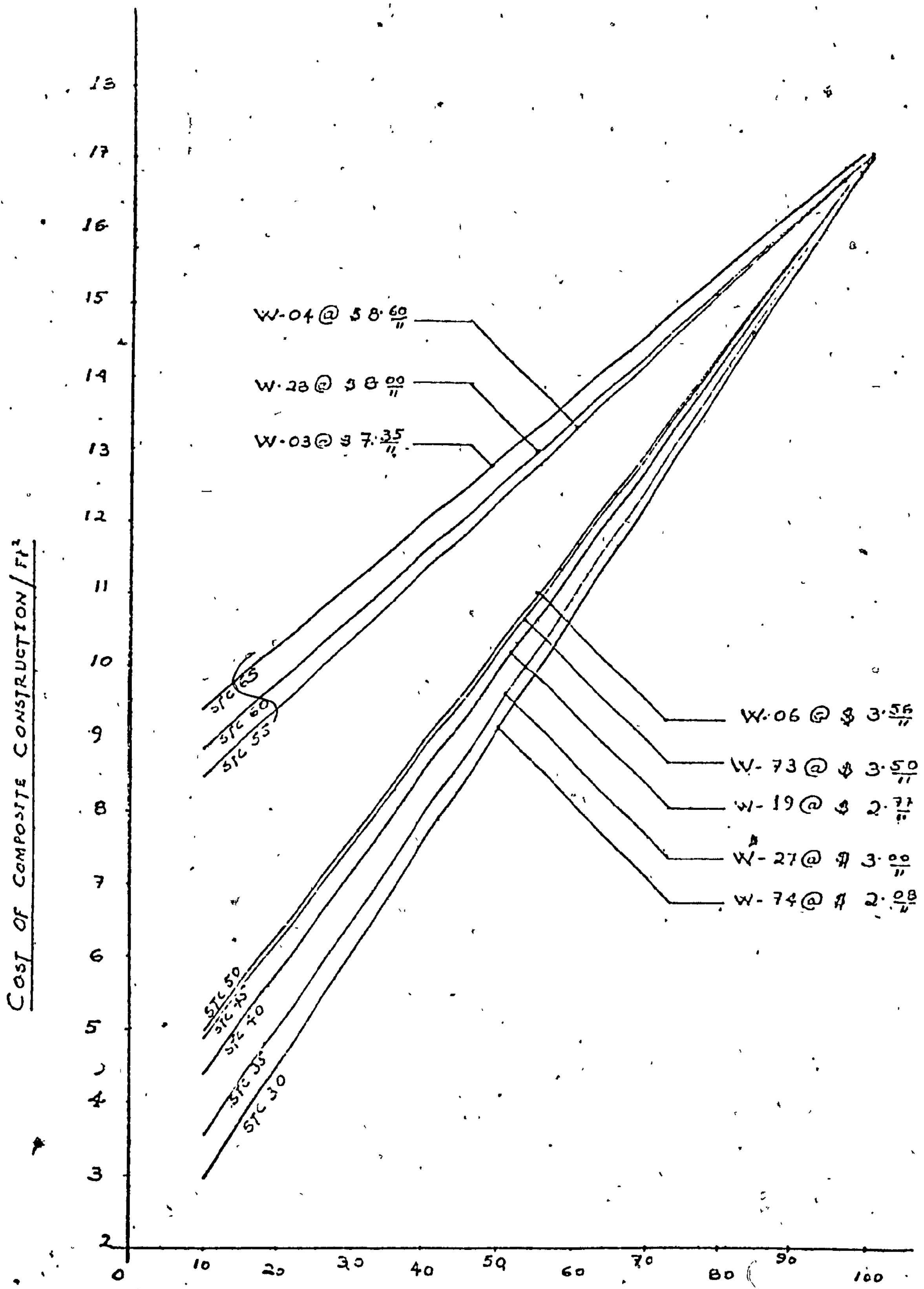


Figure 26: PERCENTAGE OF WINDOW OPENING
(DOUBLE GLAZED)
@ $ 17·00 / Ft.²

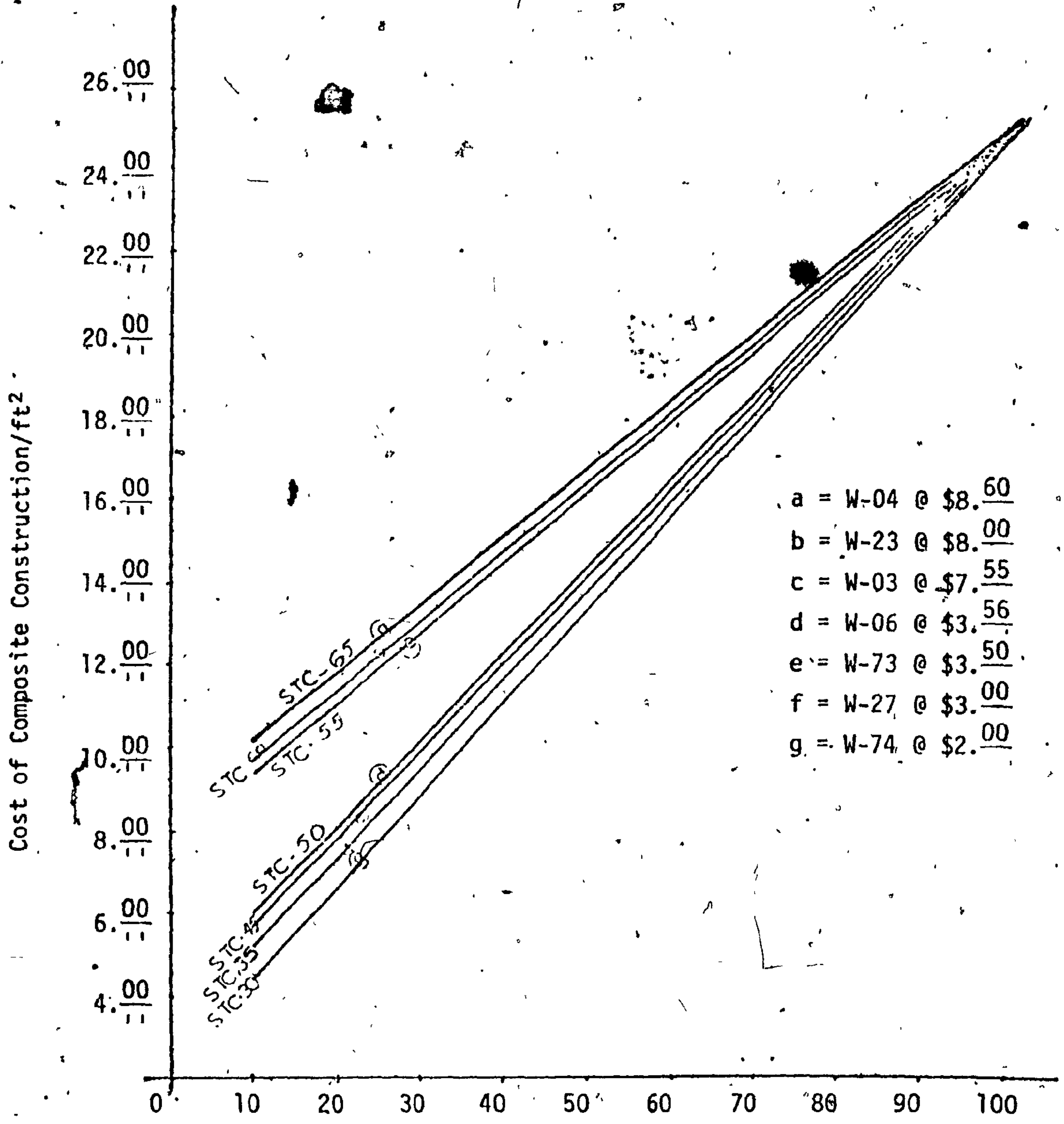


Figure 27: Percentage of window opening
(triple glazed)
@ \$25.$\underline{00}$ /ft^2

CHAPTER 6

COST IMPLICATIONS ASSOCIATED WITH APPLICATION AND ENFORCEMENT OF NOISE CONTROL STANDARDS

6.1 General

The previous chapter discussed a methodology for determining the most economical combination of wall and window to achieve a desired level of sound insulation. This chapter deals with cost implication relating to application and enforcement of Noise Control Standards with emphasis given to the California Noise Control Standards, described in Chapter 3. Some idea of the scope of the issue involved has already been indicated in the preceeding chapter.

Several general points should be noted initially. First, any attempt to answer a question on the cost implicatons of the technical contents of Noise Control Standards with actual dollar amounts is as naive and misleading as the original question is oversimplified. Implicit in the original query is the notion that there exists a criteria which can be listed and proven as necessary requirements to be met in the design and construction of multi-family dwelling. In this study an attempt is made to identify the criteria as necessary requirements, such as percentage of window opening in a given STC wall to achieve a desirable internal noise level based on considerations of occupants' needs or wants have yet to be fully established.

A more meaningful approach to the problem is to assume a cost-effectiveness approach to the provisions contained in noise control standards. Whether explicitly stated in performance terms or not, most standard provisions regarding an exterior envelope reflect some required level of performance with respect to one or more physical attributes. Associated with these performance levels are certain cost trends. If performance levels vary, it can be expected that associated costs vary also, most probably in the direction of increased costs for increased performance. Suppose in our example of Chapter 3 if we had taken desirable inside noise level as 40 dBA instead of 45 dBA. the performance of the exterior envelope would have to be increased and will result in increased cost. Conceptually, it would seem possible to develop curves for provisions contained in Noise Control Standards. There are, however, many practical difficulties and other stumbling blocks involved in an approach of this nature. The general approach, however, does have many attractive features. The issue of possible differences between noise control standard contents and requirements based on more basic considerations of occupant wants or needs (and thus of the basis on which cost consequences are determined) is put in a different perspective. Thus the various performance levels associated with standards appear as specific points on a more general cost-performance relationship with respect to some attributes. Similarly, if requirements derived from more basic considerations of occupant wants and needs are available, they would also appear as ranges or points (here we took 45 dBA as desirable internal noise level in a multi-family dwelling as specified in the California Noise Control Standard) on the same relationship. If curves of this nature could be established for external envelope of a multi-family dwelling, then it should be possible to respond the issue of cost consequences in implementing noise control standards. Another major attraction of the cost-effectiveness approach lies in its potential usefulness as an aid in actually establishing specific performance levels to be put in codified form in legal building regulations. These curves would be invaluable as a tool in the final decision-making process, a process which almost always involves a study of trade-offs. This potential usage of such curves, enclosed in this section, is extremely interesting and would generally put on a more quantified base decisions on trade-offs that are currently made, often on a rather subjective basis.

6.2 DESCRIPTION OF STUDY:

The actual study in this section proceeded along the following lines in accordance with the above concepts.

1. Multi-family dwelling units were considered for this investigation.
2. It was found to be impossible to determine cost trends without assuming outside noise level and desirable internal noise levels. Figure 11 in Chapter 4 was obtained considering 45 dBA to 105 dbA as the average outside noise level which covers all the possible outside noise level. Using Figure 11 the required average sound transmission class of the external envelope can be found to have an internal noise level of 45 dBA as stipulated by California Noise Control Standards.

Figures 14,15 and 16 were obtained with the specific intention of adhering as closely as possible to the minimum standards stipulated in Residential Building Standards, such as percentage of minimum window openings for natural light. In some instances a typical builder's house might exceed the minimum requirements for marketability purposes, eg. additional window areas would undoubtedly be included in the dining room. Hence in each type of wall a window opening of 10 to 100 percent were assumed for analysis purposes.

Since the objective of the study was to ascertain the cost impact of implementing improved Noise Control Standards, a method to determine the cost of the external envelope based on average outside noise level was developed, and displayed in Figures 25, 26 and 27. The cost curves are reported in terms of "Cost per square foot of Composite Construction". Another interesting way of interpreting the information given in Figures 25, 26 and 27 was to note the percentage of window opening in each STC value of wall could be constructed for a specified dollar amount. In this way a choice of wall and window opening could be obtained simply by choosing a more optimum configuration for prescribed dollar. It should be noted that these curves may be a useful design tool.

6.3 COST IMPLICATION OF IMPLEMENTING NOISE CONTROL STANDARDS:

Figures 28, 29 and 30 display external noise level vs unit cost of composite construction, and are the results of the study of this investigation. While constructing these figures a constant minimum of 10 percent opening was maintained, a value stipulated in Residential Standard of Canada for lighting purposes. External noises are assumed from 45 to 75 dBA for using single glazed windows since for higher than 75 dBA of outside noise level the single glazed windows are ineffective to provide an internal noise level of 45 dBA. For the same reason the outside noise levels of 65 to 90 dBA and 65 to 105 dBA are assumed for double glazed windows and triple glazed windows respectively. The data from Figure 11 displaying external noise level vs Composite TL; from Figure 14, 15 and 16 depicting percentage of window opening vs Composite TL; and from Figures 25, 26 and 27 exhibiting percentage of window opening vs cost of composite structure were correlated in the figures of this section to study the interaction between external noise level and cost of composite structure to have an internal noise level of 45 dB A. The figures were developed in order to investiage the influence of implementing improved noise control standards such as the California Standards.

Using the figures, cost of composite structure for any outside noise level can be calculated. From these figures it is interesting to note that there are undesirable cost consequences associated with higher outside noise level. As is evident from Figure 28, an STC 30 wall fitted with single glazed window of 10 percent opening can be used up to 70 dBA of outside noise level, providing 45 dBA of internal noise level; and the cost of the composite envelope would be $2.10 per square foot. While using an STC 40 wall with 20 percent glazed area cost would be $4.40 per square foot, double the cost of the previous one, for an outside noise level of 75 dBA.

Another interesting way of interpreting the information given in Figure 28 is to note the percentage of window opening and the type of wall could be constructed for a specified dollar amount for a given outside noise level. Thus when the outside noise level is 75dbA to have an internal noise level of 45dbA, for five dollars per sq. foot, one can go up to 15 percent opening in an STC 45 dB wall. It should be remembered, of course, the Internal Noise Level prescribed by Noise Control Standards are the maximum allowable, but attempts should be made to maintain internal noise level lower than the stipulated value by choosing appropriate construction.

From Figure 28, it is evident, the cost for providing a unit area of envelope is proportional to the higher external noise level, as it costs $2.60 in a 72 dBA external noise level, and $3.10 in a 76 dBA external noise level, keeping glazed area to be 10 percent in both cases.

This figure also displays the relationship between the attentuation from external noise level proportional to window area and the corresponding cost of each type of wall we are analyzing. The following examples are cited taking into consideration an internal noise level 45 dBA.

An STC 30 wall with 10 percent single glazed area could be used in 72 dbA of outside noise level and the corresponding cost would be $2.20 per square foot.

In the same wall if the window opening is increased to 20 percent, then it would be suitable only in 70 dBA of outside noise level and the cost would be $3.00. Again, if the same single glazed window area is increased to 50 percent, then the cost of composite structure would jump to $6.00 and would be suitable only to 68 dBA of external noise level.

Choosing an STC 45 wall with 10 percent single glazed area, from Figure 28, it could fit an outside noise level of 77 dBA and the cost would be $4.40; the same wall with 30 percent opening would fit 73 dBA of outside noise level and the cost could be $5.50 with 50 percent opening and for the corresponding cost of $7.00 the same wall could be used in a 70 dBA of outside noise level.

To show the interpretation of Figure 29, a double glazed window of 10 percent opening furnished in an STC 45 wall could be used in an outside noise level up to 90 dBA and the cost would be $5.40 per square foot.

If more glazed area is needed in the same outside noise level, then we can provide 30 percent opening in an STC 50 wall and the cost would be $7.40; 50 percent opening in an STC 55 wall and the cost would be $11.00; an STC 60 wall with 65 percent opening and the cost would be $12.00.

It is apparent from Figure 29 that the maximum outside noise level, using double glazed window, before California Standard needs to be enforced is 85 dBA. While implementing California Standards using an STC 40 wall with 10 percent double glazed area the cost would be $3.60 in an 85 dBA of outside noise level.

The figures can be interpreted in this way also, say, for a dollar smount of seven, the choices are 30 percent opening in an STC 40 wall in 85 dBA of outside noise level; 28 percent window area in an STC 45 wall in 88 dBA of outside noise level; 25 percent glazed area in an STC 50 wall in 90dBA outside noise level. It can be noted that an STC 40 wall cannot be used when outside noise level exceeds 92dBA; in this case higher STC value walls must be selected. Another interesting feature can be noted in the Figure 28 is using an STC 40 wall in a given outside noise level of 85 dBA, the cost could vary from $3.60 providng 10 percent window opening, maintaining the desirable internal noise level as 45dBA as the TL value for the wall and the window are the same.

In the same way triple glazed windows fitted in various STC value walls can be interpreted. (Figure 30).

The above results are a good example of the character of unit cost. The graphs can be meaningfully used for choosing the appropriate window and wall types in a given outside noise level, maintaining lower unit cost, while implementing Improved Noise Control Standards.

As a matter of interest, it is worth noting from the published results that the cost of soundproofing new dwellings to afford protection not only from noise outside but inside the building varies in the United States between 2 percent and 10 percent of the total cost of dwelling(80). In the United Kingdom, it has been calculated that to protect all houses in the country exposed to a level of traffic noise considered to be unsatisfactory (greater than 65 dBA at the front), the total cost would vary between £440 million and £1320 million ($1.2 - 3.5 billion)(81). In France, an "acoustic comfort" standard has been instituted that permits the grant of an additional 2-3 percent to low-cost housing financed by the state if their acoustic qualities are deemed to be adequate(82).

In the United Kingdom, a recent investigation included a calculation of unit costs as determined by the desired acoustic attenuation(83). According to the type of dwelling, the kind of room to be soundproofed (bedroom or livingroom) and depending on whether a ventilation system was necessary, the cost per room was calculated to vary between £80 and £130 for a noise reduction of 25-29 dBA, between £120 and £180 for one of 35-40 dBA. Often only that part of the dwelling which is exposed to a main road was found to require improved sound insulation. A study of the above nature has yet to be conducted for Canadian conditions.

In any event, it must be remembered, acoustic insulation of dwellings is not a universal remedy. It offers no protection against noise perceived outside the buildings. Furthermore, in order to be really effective, it requires an air-conditioning system and permanently closed windows, with less percentage of glazed area when compared to wall area.

FOR SINGLE GLAZED WINDOWS

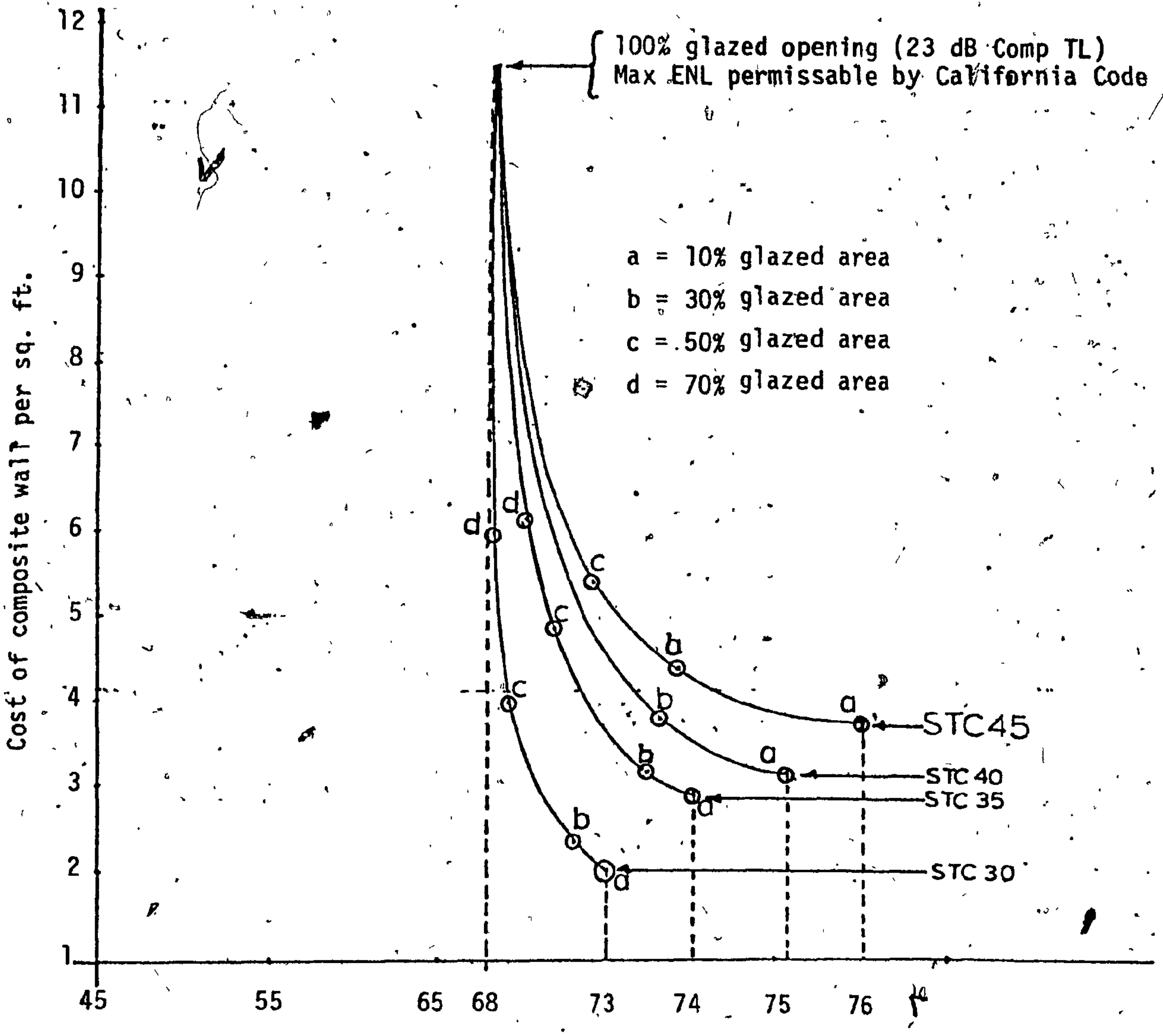


Figure 28: External noise level (ENL) in db(A)

Conclusions

1. Max ENL before California code needs to be enforced is 68 dB(A)
2. With higher ENL, appropriate curves should be used; Eg: up to 75 dB(A) STC 30 wall can be used with no openings.

   However, because of 10% opening provision, the STC 30 wall can be considered only up to 73 dB, for higher ENL, walls with more than 30 dB composite TL should be used.

-FOR DOUBLE GLAZED WINDOW

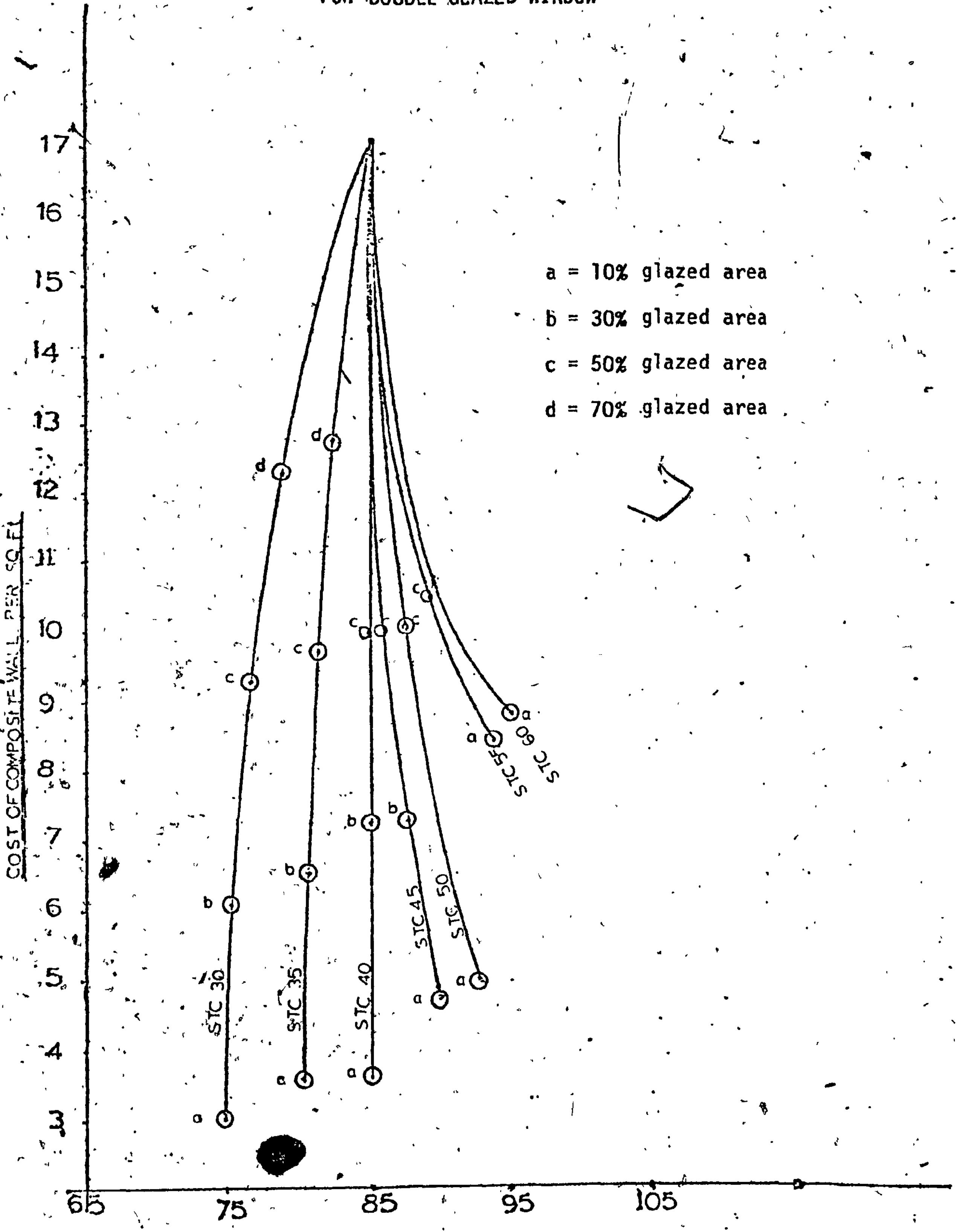


Figure 29 External noise level in dB(A)

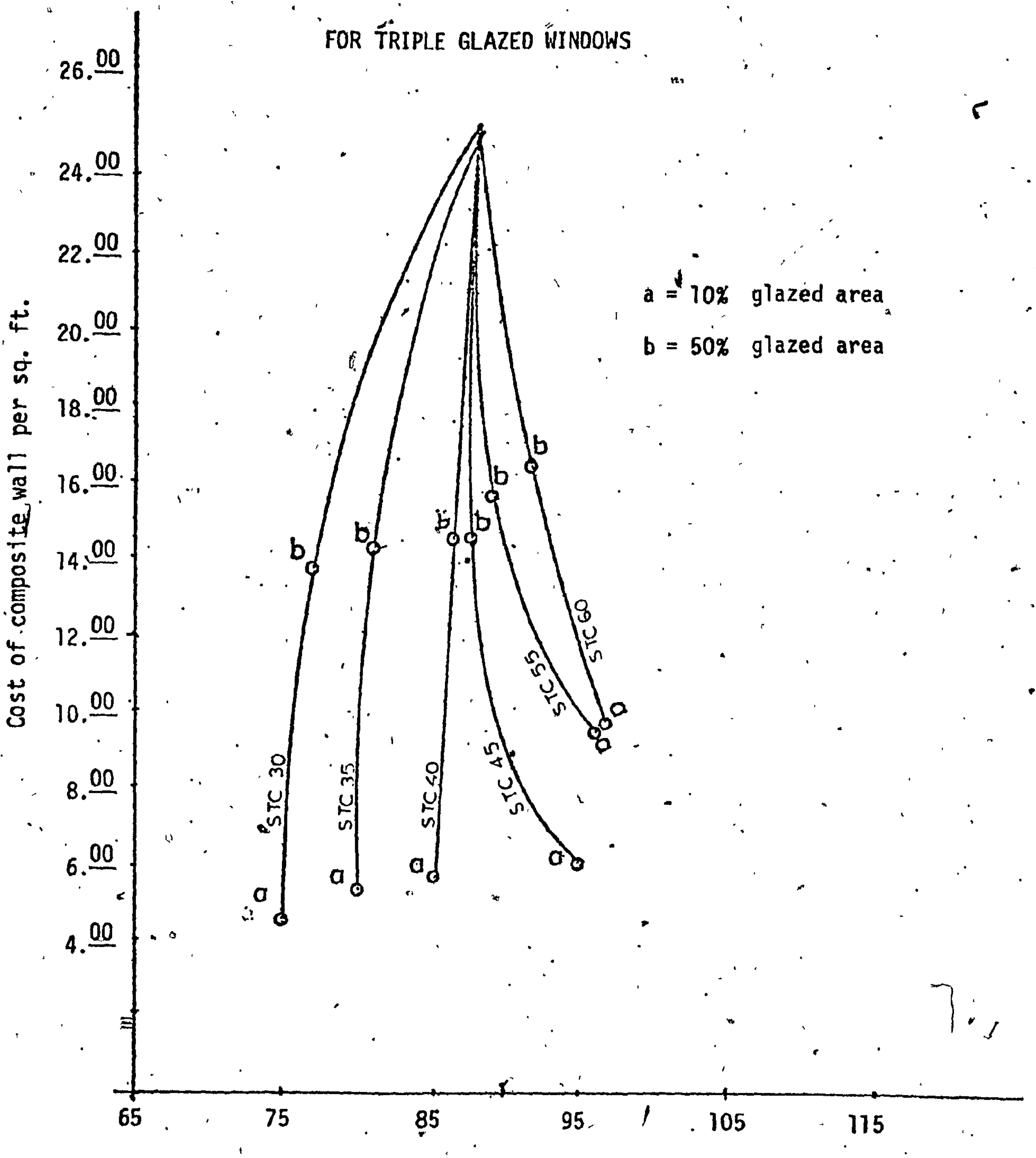


Figure 30: External Noise Level in dB (A)

Cost of STC 40 Wall

with Various Percentages of Glazed Area

Table 3

CNEL	Percentage of Window Opening	Cost of Composite Structure		
		Single Glazing $	Double Glazing $	Triple Glazing $
68	100	11.40	17.00	25.00
	50	7.20	10.00	14.20
	10	3.80	4.40	5.60
70	100	–	17.00	25.00
	50	7.20	10.00	14.20
	10	3.80	4.40	5.60
75	100	–	17.00	25.00
	50	–	10.00	14.20
	10	3.80	4.40	5.60
80	100	–	17.00	25.00
	50	–	10.00	14.20
	10	–	4.40	5.60
85	100	–	17.00	25.00
	50	–	10.00	14.20
	10	–	4.40	5.60
88	100	–	–	25.00
	50	–	–	
	10	–	–	

Cost of STC 45 Wall

with Various Percentages of Glazed Area

Table 4

CNEL	Percentage of Window Opening	Cost of Composite Structure Single Glazing $	Double Glazing $	Triple Glazing $
68	100	11.40	17.00	25.00
	50	7.20	10.30	14.20
	10	4.30	4.90	5.70
70	100	-	17.00	25.00
	50	-	10.30	14.20
	10	4.30	4.90	5.70
75	100	-	17.00	25.00
	50	-	10.30	14.20
	10	4.30	4.90	4.70
80	100	-	17.00	25.00
	50	-	10.30	14.20
	10	-	4.90	5.70
85	100	-	17.00	25.00
	50	-	10.30	14.20
	10	-	4.90	5.70
88	100	-	-	-
	50	-	10.30	14.20
	10	-	4.90	5.70
90	100	-	-	-
	50	-	-	-
	10		4.90	5.70

Cost of STC 50 Wall

with Various Percentages of Glazed Area

Table 5

CNEL	Percentage of Window Opening	Cost of Composite Structure		
		Single Glazing $	Double Glazing $	Triple Glazing $
68	100	11.40	17.00	25.00
	50	7.50	0.60	14.40
	10	4.40	5.00	6.00
70	100	-	17.00	25.00
	50	7.50	10.60	14.40
	10	4.40	5.00	6.00
75	100	-	17.00	25.00
	50	-	10.60	14.40
	10	4.40	5.00	6.00
80	100	-	17.00	25.00
	50	-	10.60	14.40
	10	-	5.00	6.00
85	100	-	17.00	25.00
	50	-	10.60	14.00
	10	-	5.00	6.00
88	100	-	-	25.00
	50	-	10.60	14.40
	10	-	5.00	6.00
90	100	-	-	-
	50	-	-	14.40
	10	-	5.00	6.00

Cost of STC 55 Wall

with Various Percentages of Glazed Area

Table 6

CNEL	Percentage of Window Opening	Cost of Composite Structure		
		Single Glazing $	Double Glazing $	Triple Glazing $
68	100	11.40	17.00	25.00
	50	9.50	12.30	16.20
	10	8.00	8.50	9.40
70	100	-	17.00	25.00
	50	9.50	12.30	16.20
	10	8.00	8.50	9.40
75	100	-	17.00	25.00
	50	-	12.30	16.20
	10	8.00	8.50	9.40
80	100	-	17.00	25.00
	50	-	12.30	16.20
	10	-	8.50	9.40
85	100	-	17.00	25.00
	50	-	12.30	16.20
	10	-	8.50	9.40
88	100	-	-	25.00
	50	-	12.30	16.20
	10	-	8.50	9.40
90	100	-	-	-
	50	-	12.30	16.20
	10	-	8.50	9.40
95	100	-	-	-
	50	-	-	16.20
	10	-	-	9.40

CHAPTER 7

CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

Most of the existing standards are in general performance standards. The California standard is one of the improved performance standards in the sense that it stipulates the desirable inside noise level. Instead of developing transmission loss measurement procedures for use in laboratories, it emphasizes and implements the concept of privacy of isolation in building by specifying the interior noise level as 45 dBA. This is what tenants really care about and what building codes should really stipulate. Instead, most of the codes give the Transmission Loss data for a number of components; if this is the case it is enough for an architect simply to search through collection of transmission loss data to choose a suitable party wall which separates the dwellings or external envelope. He must consider all the possible sound paths as well. Noise control requirements in building codes have little chance of success unless the primary objective for privacy is stated in terms of performance specification. As California Noise Control Standards are apparently one of the most stringent, in terms of field performance, it is considered for this investigation of cost analysis.

Residential standards of Canada simply state that all party walls should have a minimum STC rating of 45, ignoring the level of outside noise. Another drawback in this standard is that it doesn't say anything about wall/window ratio. Since it simply specifies the STC value of party wall; it could be possible to provide an external wall of STC 45 with 50 percent or more window opening. In this case, it will not serve any purpose for noise comfort.

It was realized that the walls in a dwelling are the major component to prevent sound incident on one side from being transmitted to the other side. In a building, windows are the weakest link conducting noise, as the insulation provided by the external wall is appreciably greater than that attainable with windows. While the cost of wall for STC 35 to STC 65 per sq. ft. ranges from $2.08 to $8.60, the cost of single, double and triple glazed windows was $11.40, $1700 and $25.00 per square foot respectively. As the cost of windows is much higher than walls, in almost every case the cost determining factor is the size of windows and the character of glazing. Walls are available in various thicknessess, consequently various TL values (and costs). So also, the windows are available single, double and triple glazed. The problem is often to pick the most economical combination that will achieve a certain required noise reduction. By using the cost curves for each wall, it may prove possible to increase the composite transmission loss with optimum window opening.

The Internal Noise Equivalent level of 45 dB(A) (as stipulated California Noise Insulation Standard) could be secured in any given external noise level by choosing the appropriate composite TL of the external envelope from the enclosed figures. The following recommendations could be made from this investigation:

- Single glazed sealed windows could be used only if the required composite TL is less than 33 dB.
- There is no great advantage of going for higher STC value walls using 10 percent single glazed sealed windows, as the composite TL increases only 32 to 33 dB by increasing STC

value of wall from 40 to 60.

- While using double glazed sealed windows of 10 percent opening the maximum attenuation possible is 50 dB.
- It is not economical to have a combination of double glazed window and wall of STC value more than 50 dB since the composite TL increases 47.5 to 50 dB by increasing the STC value of wall from 50 to 60
- The highest composite TL could be reached while using triple glazed window, with 10 percent window opening is 53 dB.
- The highest STC value of wall in which triple glazed window could be combined is 55. About this value it will not work out economically.

When the TL of windows and walls are known, a knowledge of the commonly used external envelopes enables to find out the cost of composite structure.

As the percentage of window opening is the chief cost determining factor in any envelope, the enclosed figures were developed from the calculated unit cost of commonly used walls fitted with 10 to 100 percent of single, double and triple glazed windows in each wall. The various combinations of wall and single glazed window combinations for an average TL of 30 and the corresponding costs are:

STC 35 wall	14% opening	$3.50
STC 40 wall	17% opening	$4.00
STC 45 wall	18% opening	$4.50
STC 55 wall	20% opening	$8.30

from this example it could be seen that there is not much advantage of going for higher STC value walls without restricting the glazed area. Using double glazed window and wall combinations to achieve a 45dBA of internal noise level are \$13.00 /ft^2 using STC 30 wall; \$3.50 using STC 35 wall; \$4.40 using STC 40 wall.

The cost curves could be interpreted to note the percentage of window openings in each STC value of wall could be fabricated for a specific dollar amount.

Thus for a dollar amount of five, using single glazed windows, 16 percent opening in a STC 50 wall, 20 percent opening in STC 45 wall; 22 percent opening in a STC 40 wall; 30 percent opening in a STC 35 wall; 33 percent opening in a STC 30 wall can be achieved. Hence, a choice of wall and window opening could be obtained simply by choosing a more optimum configuration for a prescribed dollar.

It is evident from this investigation, the cost for providing a unit area of envelope is proportional to the higher external noise level, as it costs \$2.60 in a 72dbA external noise level and \$3.10 in a 76dbA external noise level, keeping glazed area to be 10 percent in both cases. This figure also displays the relationship between the alteration from external noise level proportional to window area and the corresponding cost of each type of wall analyzed.

The figures also display the relationship between the outside noise level and the corresponding cost in this region, to implement an improved noise control standards such as California Noise Control Standards. For example, to have a 45 dBA of internal nosie level a STC 30 wall with 10 percent single glazed area could be used in 72 dBA of outside noise level and the corresponding cost would be $3.00 again, if the window opening is increased to 50%, then the cost of composite structure would be suitable only to 68 dBA of outside noise level and the cost would be $6.00. Instead a STC 45 wall with 10 percent opening, suitable for 77 dBA of outside noise level would cost $4.40; the same wall 30% opening could fit 73 dBA of outside noise level and the cost would be 5.50; with 50 percent opening and $7.70 of corresponding cost of the same wall could be used in 70 dBA of outside noise level.

Evaluation of the Limmitations of the Study

1. The equation used to calculate the composite TL of each construction (Ch.4,p77) is based on the assumptions that each system is effectively one dimensional, homogeneous and of infinite extent. Thus the curves given in Figs. 14 to 16 are subject to the following limitations:
    a) the effect of different window geometry for a given window/wall ratio is not taken into account. On the microscopic scale investigated this should not be a significant factor.
    b) The implied assumption that all elements of the composite construction transmit power equally, when in fact due to the finite nature of the actual construction, this is obviously not so, has the effect of making the presented composite TL's, in fact, conservative.

2. Room effects were not considered in this study, even though for a normal room with average absorption obtained through furnishings and carpeting, this correction would increase the effective TL of the composite construction.
3. The use of the STC of a construction was chosen for the measure of the TL even though the particular ASTM Standard (E413-70T) used to determine, recommends against using this measure because of assumptions about spectral balance of the noise signal used in the derivation of this measure. There were two reasons for using STC as the measure of sound insulation of the partition; the first reason, as explained in Section 4.4, is the relation between the STC contour and the A-weighted noise level. As this study was primarily concerned with an exterior noise level expressed in dBA, it was felt that the STC provided sufficient information to evaluate and compare different construction. The second reason is one of practicality, as the STC is the measurement that most manufacturers use as a rating of their products, and thus STC ratings were availalbe for use for a wide range of existing constructions. Thus, using the STC as the measure of noiseinsulation provided a practical measure that can easily be related to practice.
4. In this investigation, sealed window units (single, double or triple glazed) are considered. The cost implications of this are not explicitly calculated in this study as the focus was on the capital cost of acoustical performance alone. The major additional cost of such construction would be the obvious

requirement of mechanical ventilation, although this would be somewhat offset by the improved thermal performance of sealed units, as compared to openable ones. As only capital cost is considered, additional cost items, such as maintenance cost, are also excluded.

5. The California Noise Insulation Standard stipulates 45dBA as the users' requirement for interior acoustical comfort. In this study, the sound transmission loss (expressed as STC value) of the exterior envelope alone was considered, in an attempt to quantify the sound insulation required and resulting cost differential as the outside noise level varied on a rather course scale. In a particular design application, the ambient noise, due to structure borne sound, flanking noise and construction details, as well as the actual spectral content of the ambient noise, must be taken into consideration. As such, the results of this study present design guidelines which can narrow the range of constructions to be evaluated on a more detailed basis as final design choices.

The following recommendations could be made from this investigation:

(a) The conventional multi-family construction provides at least 20 dBA of noise reduction with windows closed; therefore, compliance with the standards in areas where the exterior CNEL is not greater than 65 dBA does not require special treatment.

(b) Up to 90 dBA of CNEL there is not much advantage in using triple glazed windows as double glazed windows provide the required TL with comparatively lower costs.

(c) Generally, single glazed sealed windows could be used only up to 68 dBA of CNEL.

(d) Considering the acoustic comfort, the cost implications are secondary while implementing a performance standard specifying the interior noise level. Hence, there is no reason why such a standard should not be implemented to have a better comfort to the community.

(e) These standards would enable the designers to be aware of the acoustical comfort of the dwellers and the environment at the planning stage itself.

In line with this investigation, the following suggestions could be made for further studies:

(1) Developing an improved standard for structure borne noise.

(2) An investigation of cost analysis, in terms of percentage of increase of the total cost of new dwelling of sound proofing to afford protection not only from outside but inside the building as well.

(3) Studies to obtain unit costs to attain acoustic attenuation.

(4) Studies to attenuate outside noise level in old multi-family dwellings.

References

1. Baron, R.A., The Tyranny of Noise, Harper Colophon Books (1970)
2. Richardson, H.W., Urban Economics, Penguin Books, Harmondsworth (1971)
3. Warren Springs Laboratory, National Survey of Air Pollution, 1961-71, HMSO, London (1972)
4. Hall, P.G., Regional Planning and Airport Location, Conference on World Airports, The Way Ahead, Institute of Civil Engineers, London (1969)
5. Smith, P.S., A Study of the Economic and Social Effects of Major Airport, with special reference to Heathrow Airport, University of London, M. Phil, thesis (1967)
6. Noise Control in Multi-family Dwellings; U.S. Department of Housing and Urban Development, Washington (1976)
7. John J. Van Houston, California's Noise Insulation Standards, Noise Control Engineering, September - October 1975, Vol. 5, p. 54
8. Daniel L. Schodek, The Influence of Building Codes Housing Cost: Interim Report prepared for the Department of Architecture, Harward University, 1974.
9. Sealy, K.R., Air Transport Facilities and Regional Planning, The Aeronautical Journal, Vol. 74, p. 703 (1969)
10. Miller, J.D., Effects of Noise on People, J. Acoust. Soc. Amer. (1974), Vol. 3, p. 27.

11. Davis, H. and Kranz, F.W., The International Standard Reference Zero for Pure Tone Audiometer and its Relation to the Evolution of Impairment of Hearing, J. Speech Hear, Vol. 7, p. 87, 1964

12. EPA (U.S. Environmental Protection Agency). Informlation on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, Washington, March 1974.

13. AAOO (American Academy of Opthalomology and Otolargnygology) Guide for Conservation of Hearing in Noise, A supplement to the transcations, revised 1964

14. Glorig, A., The Problem of Noise in Industry, American Journal of Public Health

15. Bursn, W. and Robinsin, D.W., Hearing and Noise in Industry, London, HMSO, 1970

16. McKennell, A.C., Aircraft Noise Annoyance Around London (Heathrow) Airport, Central Office of INformation, SS337, April 1963

17. Thiessen, G.J. and Olson, N., Community Noise - Surface Transprotation, Sound and Vibration, Vol. 2, p. 29, 1968.

18. Schieber, J.P., Etude Analytique en Laboratoire de L'influence du Bruid sur le Sommeil Rapport, DORST - Centre d'etudes Bioclimatiques du CHRS, Strasbourg, 1968

19. Van Meirhaeghe A., Le Bruit dans Notre Environnement Urbain, Revue Belge D,Harmanism Medicals, Juileet - Octobre 1976.

20. Lukas, J.S. and Kryter, K.D., A Preliminary Study of the Awakening and Startle Effects of Simulated Sonic Booms, NASA Report No. CR-1193, 1968.

21. Sharpel, S. and Jaspter, H., Habituation of one Arousal Reaction Brain, 1956.

22. Shatalov, N.N. et al, On the State of the Cardiovascular System under Conditions of Exposure to Condinuous Noise, Transcript from Gigiena Trudi i Professional 'rige Zabolevaniya, Moscow, 1962.6

23. Connell, J., The biological Effects of Noise, British Association for the Advancement of Science, May 9, 1972.

24. EPA (U.S. Environmental Protection Agency) Effects of Noise on People, Washington, December 1971.

25. Levi, L., Life Stress and Urinery Excretion of Adrenaline and Noradreline, in W. Raab (Ed), Prevenstion fo Ischemiac Heart Disease, 1966.

26. Bell, A., Noise: An Occupational Hazard and a Public Nuisance, Public Health Paper, No. 30, Geneva: World Health Organization, 1966.

27. Davis, R.C., Electrical Skin Resistance before, during and after a Period of Noise Stimulation, Journal of Experimental Psychology, 1967, Vol. 15, p. 65

28. Janden, G., Zur Entstebuhn Vegitativer Funktionsstrurgan durch Larminwirsy, Archiv. Generberpath u. Gewerbehyg 1959.

29. Shultz, T.J., Some Sources of Error in Community Noise Measurement, Sound and Vibration, 1975, Vol. 2, p. 34.

30. Safeer, H.B., Wesler J.E. and Rickley E.J., Errors due to Sampling in Community Noise Level Distributions, Journal of Sound and Vibration (1972), Vol. 2, p. 30

31. Schultz T.J., Instrumentation for Community Noise Surveys, Inter-Noise 73, Proceddings of International Conference on Noise Control Engineerng, Copenhagen.

32. Fisk, D.J., Statistical Sampling in Community Noise Measurement, Journal of Sound and Vibration (1963) Vol. 3, p. 67.

33. Rosenblith, W.A.-_Stevens, K.N. and Bolt Beranek and Newmen Inc., 1953 in Handbook of Acoustic Noise Control.

34. Farrack, N.O., Cummunity Reaction to Noise in Handbook of Noise Control: McGraw-Hill book Company, Inc. (1957)

35. Stevans, K.N., :Procedures for Estimating Noise Exposure and Resulting Community Reactions from Air Base Operation, Ohio, 1957.

36. Galloway, W.J. and D.E. Bishop, Noise Exposure Forecasts (1920)

37. Noise Stnadards: Aircraft Type Certification: Federal Register 1969.

38. U.S. Environmental Protection Agency: Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure (1973)

39. U.S. Environmental Portection Agency: Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety (1974)

40. Patrick F. Cuniff, Environmental Noise Pollution, John Wiley & Sons, 1977.

41. George Bugliarello, The Impact of Noise Pollution, Pergman International Library, 1976.

42. Donley, "Community Noise Regulation", Sound and Vibration, February 1974, Vol. 11, p. 4.

43. Jiri Tichy, Noise Standards from the Perspective of International Standards Organization, Noise - Con 73.

44. ISO: ISO/TC 43 (secretariat - 275) 405, Draft proposals, February 1971

45. Aeronautics Act, RSC 1970 Ch. a.3, Sec. 6.

46. Railway Act RSC 1970, Ch. P2

47. Motor Vehicle Safety Act RSC 1970, Ch. 26

48. Canada Labor Code RSC 1970, C.L.-1

49. Judith Reed, The Auditory Environmental Crisis, Technical Report, Cornell University, USA, Fall 1973.

50. Vehicle and Traffic Law, Ch. 775 of the Laws of 1959, as amended.

51. Environmental Protection Act, S.O. 1971, Ch. 86 as amended.

52. Regulation Concerning Snowmobiles, Que. State and Reg., Jan. 1973.

53. Transportation Act. S.Q. 1972.

54. Public Health Act, PSQ, 1964, C. 161

55. Model Municipal Noise Control By-law: Revised May 1976, Ministry of the Environment, Ontario

56. Boston, Massachusetts, Ordinance, adopted September 30, 1850

57. Edward F. Brown, et al, City Noise: Noise Abatement Commission, N.Y. Department of Health, New York, Acadamy Press 1930.

58. Laws and Regulatory Schemes for Noise Abatement, U.S. Environmental Protection Agency, Washington, D.C., GPO, 1971.

59. Seattle, Washington, ordinance adopted May 14, 1952.

60. Cincinati, Ohio, ordinance adopted October 30, 1953.

61. Chicago, Illinois, ordinance adopted March 10, 1975.

62. Department of California Highway Patrol, Vehicle Code Section 23 130 and 27 160, 1967.

63. Boulder, Colorado, ordinance adopted Jan.1 1970.

64. Inglewood, California ordinance adopted, November 1969.

65. Chicago, Illinois, ordinance adopted July 1, 1972.

66. S. Lwin Law and the Municipal Ecology, MLO Report 1970

67. Municipal Noise ordinance, California League of Cities, 1971.

68. C.R. Bragoon, "Noise Control Legislation", Noise Expo. 1973.

69. William S. Gatley, Regulation for Noise in Urban Areas, University of Missouri - Rolla, 1973.

70. Noise Control in Multi-family Dwellings, Sub-article 12090, 0, Local Law #76, New York City, 1968.

71. John J. Van Housten, "California's Noise Insulation Standards", Noise Control Engineering, September - October 1975.

72. Duerden, Noise Abatement, Philosophical Library, Inc., New York (1971)

73. ASTM E 90-70, "Recommended Practice for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions", American Society for Testing and Matierals, Philadelphia

74. Cunniff, Environmental Noise Pollution, John Wiley and Sons, Inc., (1977).

75. Rettinger, Acoustic Design and Noise Control, Chemical Publishing Co., Inc., New York, (1973)

Appendix A - Assessment of Community Noise

A community noise assessment programme, in accordance with the investigation of the economical aspect of implementing California Noise Standard was undertaken in the location of St. Catherine and Guy Streets. This assessment was used to provide raw data with respect to a glazing cost benefit study discussed earlier.

Single Event Noise Exposure Level (SENEL) and Community Noise Equivalent Level (CNEL)

In a community, the summation of annoyance for single event noise leads to a reaction to noise from those sources. Thus, it becomes important to find a way to rate single event noises, such as the noise from a car or from an airplane flyover, perceived at a given distance from the source. To do so, a Single Event Noise Exposure Level (SENEL)[1] has been introduced, which integrates over the entire duration of the noise - as perceived at a given distance fromthe source - the A weighted noise generated by the source.

---

[1] For noise for a single aircraft SENEL $NL_{max} \pm 10 \log_{10} \tau/_2$ dBA, where NL_{max} is the maximum ovserved noise level (on the -A scale) and τ is the duration measured between 2 points 10 dB before and after the maximum noise.

For surface vehicles (automobiles, trucks, etc.) moving at velocity V and approximate formula for SNEL is (EPA, 1976) : SNEL = La (R) + Log $[(\Pi/_2)(R/_V)]$ dB is $20_{\mu N}$ per m^2 and per second, where La is the A-weighted noise level at distance R.

The total noise exposure for a day (24 hrs) is the community noise equivalent level (CNEL). It is recognized that a given level of noise may be more or less tolerable, depending on the length of time an individual must endure it. The State of California Department of Aeronautics and the Commission of Housing and Community Development have adopted the CNEL measure of noise. This measure considers an A-weighted average noise level for the hours between 7:00 p.m. and 10:00 p.m. increased by 5 dB: and the late evening and morning hour noise level from 10:00 p.m. to 7:00 a.m. increased by 10 dB. The daytime noise levels are combined with these weighted levels and averaged to obtain a CNEL. More explicitly, this is stated by the following:

$$\mathrm{CNEL} = 10 \log (1/24)[\Sigma \text{ antilog } \mathrm{HNLD}/10 + 3\Sigma \text{ antilog } \mathrm{HNLE}/10 + 10\Sigma \text{ antilog } \mathrm{HNLN}/10]$$

where

HNLD is the hourly average A-level from 7 a.m. to 7 p.m.

HNLE is the hourly average A-level from 7 p.m. to 10 p.m.

HNLN is the hourly average A-level from 10 p.m. to 7 a.m.

<u>Location</u>

The roof top of Canest Building overlooking the south east corner of St. Catherine and Guy Streets was selected as a typical location to assess.

Final Result and Comments

The observed hourly values were measured and the CNEL calculated for the location was found to be 73 dBA. In this investigation, the residual noise level drops sharply after midnight, reaching a minimum value between 4:00 a.m. and 5:00 a.m., thereafter, the residual noise level raised between 6:00 a.m. and 8:00 a.m. to almost constant daytime value.

This diurnal cycle for the community noise level is well correlated with human activity, and particularly with the amount of vehicular traffic; this can be considered the basic source of the residual noise level at this locality.

In general, residential units should not be located in areas where CNEL is greater than 65 dB. Barriers should be located between the noise source and the residential property to reduce the CNEL to at least 65 dB. This location is not ideal for residential location, without special treatment.

The construction of conventional multifamily dwelling provides 20 dB alternation when windows are closed, therefore, while implementing California Noise Insulation Standard where the CNEL is no greater than 65 dBA does not require speical treatment. When the CNEL is in the range of 65 dBA to 70 dBA, construction normally involves the use of fixed or double glazed windows, relocated or muffled vents, and tightly fitted weatherstripped doors, which are buffered by an entry way of wing-wall.

Community Noise Equivalent Level (CNEL)

$$\mathrm{CNEL} = 10 \log (1/24 [\Sigma \text{ antilog } \mathrm{HNLD}/_{10} + 3\ \Sigma \text{ antilog } \mathrm{HNLE}/_{10} + 10\ \Sigma \text{ antilog } \mathrm{HNLN}/_{10}]$$

where

HNLD is the hourly average A-level from 7 a.m. to 7 p.m.

HNLE is the hourly average A-level from 7 p.m. to 10 p.m.

HNLN is the hourly average A-level from 10 p.m. to 7 a.m.

$$\mathrm{CNEL} = 10 \log [1.0990851 \times 10^8 + 3\times 10202670 + 10\times 36365154]$$
$$= 73.22 \text{ dBA}$$

Appendix B Noise Legislation Abroad

Louder noise levels, more sources of nuisance, modern construction using lightweight building techniques and increased concern with amenity are reflected in requirements for sound insulation and noise control building regulations and codes of many nations. In this section, the attention of architects, builders and structural engineers is drawn to some of the more important regulations and codes relating to sound insulation in different countries. For their guidance, extracts from some of the more important codes are given with references to other legislation. Names and, where appropriate, addresses of regulating authorities are also given.

United Kingdom

[There are essential differences between building regulation in Scotland and England and Wales.] In Scotland, following the report of the Guest Committee on Building Legislation, in 1957, a National Building Act and National Building Regulations replaced in 1963 local acts and bylaws. The Guest Report, in recommending that regulations should include resistanct to sound transmission between dwellings, noted that they might, in the future, have to deal with sound transmission between rooms within a dwelling and even with the containing of sounds within a building. The report stressed the importance of laying the foundations for an extension of noise control requirements, "all the more because of modern conditions of living were making it more and more necessary in the interest of health for a greater degree of quietness in houses."

Sound insulation is dealt with in Part VII: Resistance to the Transmission of Sound, of the Building Standards (Scotland) Regulations, 1963. Unlike some other sections of the regulations, the requirements for sound insulation relate only to new works, ie local authorities cannot require existing buildings to conform to the sound insulation regulations. Regulation 104 identifies and defines separating walls and floors - ie a wall separating a house (a dwelling) from any other building, or a wall or floor forming part of a building from any other part of that building. It then specifies by means of Table 2 (Part I) minimum sound reduction levels for airborne sound which the construcion of a separating wall or floor 'in conjunction with other parts of the structure of the building in association therewith' must provide.

It further requires that a separating floor shall be constructed so that 'in conjunction with other parts of the building in association therewith' the floor limits the impact sound transmission so that when a sound field is generated in that part of the building by the standard impact method, the sound pressure levels produced in any part of any house do not exceed the values in Part II of Table 3 at all frequencies stated therein.

It will be noticed that the sound reduction figures are specified for a range of frequencies from 100 to 3200 c/s.

The following is Table 12 of Building Standards (Scotland) Regulations, 1963.

Table 2 - Levels of Sound Insulation in Houses

Part I - Airborne Sound

Frequency in Cycles/sec.	Minimum Sound Reduction in Decibels	
	Separating walls - houses other than flats	Separating walls and floors - flats
100	40	36
125	41	38
160	43	39
200	44	41
250	45	43
320	47	44
400	48	46
500	49	48
640	51	49
800	52	51
1000	53	53
1250	55	54
1600	56	56
2000	56	56
2500	56	56
3200	56	56

2

Table 3 - Levels of Sound in Houses

Part II - Impact Sound

Frequency in cycles/second	Maximum octave-bands sound pressure levels in decibels for separating floors - flats
100	63
125	64
160	65
200	66
250	66
320	66
400	66
500	66
640	65
800	64
1000	63
1250	61
1600	59
2000	57
2500	55
3200	53

To make allowance for the possibility that a reading or readings at a particular frequency or set of frequencies may fall marginally below the minimum specified in the Table, Regulation 104 also states that a construction 'shall be accepted as meeting the requirements . . . if, on a reading being taken at each of the frequencies set out in the said Part I, (or, for impact sound, Part II), the aggregate of any amounts by which the reduction of airborne sound falls short of (or, for impact sound, the sound pressure level exceeds) the value given in the said Part I (or Part II) does not exceed (is not greater than) 23 decibles.'

It will also be noticed from Table 12, Part I that, for airborne sound, the minimum sound reduction for separting walls in houses is set at a higher level, especially in the lower frequencies, than that for a separating walls and floors in flats.

For the purposes of Regulation 104, "standard impact method" means the method of generating a sound field described in clause 5a of the British Standard Bs 2750; 1956, "Recommendations for field and laboratory measurement of airborne and impact sound transmission in buildings," used in relation to a floor."

Regulation 105 of the Scottish Building Regulations specifies in some detail the way in which measurements in buildings to check compliance with Regulation 104 shall be carried out. First, it requires that 'where the construction of any part of a wall or floor differs from that of the remaining part ot that wall or floor, each part shall be treated for the purposes of this regulation as a separate wall or floor.'

It also allows every wall or floor in a building with nominally identical construction to be treated as forming part of a single wall or floor, as the case may be. Measurements again are specified as being in accordance with Bs 2750 section 2 and 3; 'the method of normalizing results for both airborne and impact sound shall be that given in clause 3e (ii) of the British Standard.

Regulation 105 (3) deals with the way measurements may be averaged when a separating wall or floor serves one or more flats. Where a wall or floor in any building separated one or more pairs of apartments the value of the sound transmission of that wall or floor shall be taken as the average of the measurements between apartments separated by wall or floor as follows:

(a) Where the wall or floor separates four pairs of living rooms, the measurements between those four pair;

(b) Where the wall or floor separates more than four pairs of living rooms, the measurements between such of those pairs of rooms, being not less than four, as many may selected by the building authority;

(c) Where the wall or floor separates less than four pairs of living rooms but separates other pairs of apartments, the measurements between the pairs of living rooms and such other pairs as may be selected by the building authority, being in any case such a number as will bring up the number tests to not less than four.

(d) Where the wall or floor separates less than four pairs of apartments, the measurements between those pairs of apartments.

Besides these requirements based on standard methods of sound transmission measurement, the Scottish regulations list specific construction which are deemed to satisfy the requirements of Regulation 104. The specifications in Schedule 9 of the 1963 Regulations. (Uses of this schedule should first refer to Part A. Interpretation of Schedule 9). The schedule gives specifications for five alternative forms of solid wall construction:

i) plastered brickwork, minimum weight 100 lb/sq.ft.
ii) plastered dense concrete, minimum weight 95 lb/sq.ft.
iii) plastered dense concrete blockwork, minimum weight 95 lb/sq.ft.
iv) plastered no-fines concrete, minimum wieght 90 lb/sq.ft.
v) plastered sandstone

Three alternative forms of cavity wall construction are also specified:

i) plastered cavity brickwork, minimum weight 100 lb/sq.ft.
ii) plastered cavity dense concrete blockwork, minimum weight 95 lb/sq.ft.
iii) plastered cavity clinker concrete blockwork, minimum weight 50 lb/sq.ft. (here a 3 inch cavity is required)

For the walls of flats only, four other forms of construction are allowed. Two are of solid construction:

i) plastered dense inside concrete, minimum weight 85 lb/sq.ft.
ii) plastered blockwork of autoclaved aerated concrete, minimum weight 50 lb/sq.ft. (here a cavity of 3 inches is required and there are also requirements relating to the aerated concrete).

Schedule 9 also gives specifications for there alternative forms of concrete floor construction and one form of timber floor construction which are 'deemed to satisfy' the requirements for separating floors. In addition to a resilient finish on a 6 inch solid concrete slab (minimum weight 75 lb/sq.ft.) two forms of floating floor - wood rafter concrete screed - are specified for use with four alternative forms of solid or hollow concrete construction. The timber floor construction specified includes a floating wood raft, granular deafening (minimum weight 17 lb/sq.ft.) and a heavy plastered ceiling. Resilient layers required to be used with floating floors have to conform to British Standard Code of Practice CP 3: Chapter III (1960) Sound Insulation and Noise Reduction (Appendix B, para 7 (d), retaining their resilience under imposed loading.

The Scottish Development Department, Edinburgh, is the responsible control authority concerned with building regulation. The administration of the regulations is a responsibility of local authorities: landward areas. There is a Scottish Laboratory of the Building Research Station at Thorntonhall, Glasgow.

England and Wales

When national building regulations for England and Wales (1965) were introduced, requirements for sound insulation in building were made for the first time.

The English Regulations (Part G: Sound Insulation) are framed in very general functional performance terms followed by 'deemed to satisfy' provisions within the body of the regulations. These clauses specify methods and materials of construction which meet the functional requirements.

The regulations differ from those in use in Scotland in that they specify neither minimum sound reduction values for airborne or impact sound nor methods of measurement to control compliance.

Regulation G1 is concerned with the sound insulation of walls. The regulation deals first with walls separating one dwelling from another dwelling. It then deals with walls separating a habitable room in a dwelling from any other part of a building which:

i) is not used exclusively with that dwelling; and

ii) is a place used for purposes other than occasional repair or maintenance, or is a machinery room or tank room.

There are special requirements where a wall serves to separate a dwelling from a refuse chute which in effect prevents the placing of a chute near to a living room or bedroom. It can, however, be located next to a kitchen if the separating wall has an average weight of not less than 45 lb/sq.ft.

Regulation G3 is concerned with the sound insulation of floors. In this case, there is a distinction between floors which have to provide sound insulation against airborne and impact sound and those which only need to provide insulation against airborne sound. Adequate insulation against airborne and impact sound must be provided in floors below which there is a dwelling. Only insulation against airborne sound need be provided where there is a dwelling above the floor and a common area, or machinery or tank room, below. As with separating walls, floors separating dwellings from rooms only occasionally used for repair or maintenance are exempt from sound insulation requirements.

In the English Regulations, sound insulation is regulated first by specifying those parts of a building separating walls and floors as defined in Regulations G1 and G3 summarized above - which 'shall be so constructed as to provide adequate resistance to the transmission of airborne and impact sound'. A number of specifications 'deemed to satisfy' these requirements are then given. Unlike the Scottish Regulations, there is no reference to standards of performance in terms of minimum sound reduction in decibels, or for impact sound, maximum octave-band sound pressure level in decibles. Methods of measurement of sound transmission are not specified.

The intention of Regulation G2, which gives specifications for three types of solid wall constructions and two types of cavity constructions is understood to be that all separating walls in a dwelling should have a standard of sound insulation equal to the Building Research Station house party wall grade. Also, the intention of Regulation G4, which gives specifications for three types of floor meeting impact and airborne sound requirements and are meeting airborne sound requirements only, is that all separating floors in dwellings should have a sound insulation of Grade I performance. It should be noted that the regulations differ from those for Scotland in that in England and Wales, all party walls are expected to satsify the house party wall grade while, in Scotland, this standard is only required for houses, the slightly lower standards of Grade II being acceptable in flats for party walls as well as for party floors.

Traditional construction may be defined as mainly load bearing walls of brick or block or in-site concrete construction, for both the separating and the external flanking walls. For solid separating walls of any material, a minimum weight of 85 lb/sq.ft. (415 kb/sq.in.) is advisable to be reasonably sure of reaching the party-wall grade. For cavity walls, cavity walling of two half-brick leaves, separating a 2 inch (50mm) cavity was formerly recommended for party wall, on the basis of the higher single-figure insulation. Cavity wall construction of this type is 'deemed to satisfy' the requirements of GI of the English Building Regulations. However, in Digest 102 Building Research Station has noted that 'all available evidence now shows cavity construction has no sensible advantage over the one-brick solid wall; indeed, unless the cavity wall is maintained as a minimum and with ties of butterfly pattern are used, the party-wall grade will not be attained.

For separating floors between flats, a concrete sub-floor of not less than 45 lb/ft.sq. (220 kg/m.sq.) with a floating floor, is considered necessary to achieve the Grade I standard. Alternatively, a concrete sub-floor of not less than 75 lb/sq.ft. (365 kg/m.sq.) with a soft floor finish instead of a floating floor can give this standard. Under certain conditions, the lumber alternative of a sand-pugged and floating wood-joist floor may also give the Grade I performance.

Non-tradiational forms of construction, for example, systems of light-weight type where weight is replaced by wide cavities and structural insulation, can, in certain circumstances, provide an equivalent reduction in sound transmission.

In England, the Ministry of Housing and Local Government and, in Wales, the Welsh Office, Cadrift, are the control authorities responsible for building regulations. The administration of regulations in the field is a responsibility of borough and district councils - urban and rural. In inner London, however, design and construction of buildings is subject to the requirements of the London Building Act.

Scandinavia: Denmark, Norway and Sweden

Design and construction of buildings are regulated under the authority of fairly recent building laws: Denmark, 'Byggelow for Købstaederne og bandet 1960 and 1968 - there is separate legislation for the capital city; Copenhagen; Norway Bygringsloven 1965 and Sweden, Byggnadslag 1947 and 1967. These laws empower the responsible control government authorities Housing Ministry, Denmark; Department of Municipal Affairs, Norway: and Board of Urban Planning, Sweden - to make national regulations. These include regulations relating to insulation against noise in buildings, particularly dwellings. National Regulations have been issued in Denmark and Sweden. In Norway, draft regulations have been prepared. Below, the main requirements of the Danish and Swedish regulations are listed.

DENMARK

Chapter 9 (Lydisolering) of the National Reguations 1966 is concerned with sound insulation. There are three sections. The first deals with general requirements, mainly the specification of methods for measurement of sound insulation against airborne and impact noise. Here, the use of ISO Recommendations R140; Field and Laboratory Measurements of Airborne and Impact Sound Transmission (1960) is specified, measurements being corrected to a 1/2 second reverberation time in the receiving room. Noise level meters meeting requirements of IEC Publication 179 are to be used. A local building regulation authority is empowered to require field measurements to be made in new buildings to check compliance with the regulations. In circumstances where there is a risk of noise from equipment used in commercial premises causing a nuisance to an adjoining dwelling, the local authority may make special and more rigorous requirements.

The second section deals with sound insulation in dwellings. In turn, the regulations deal with the level of sound insulation between rooms in separate buildings, airborne sound reduction for separating walls and floors, and for doors separating a dwelling from a common (public) lobby or staircase, impact sound reduction, reverberation time in common lobbies and staircases and noise from mechanical equipment. Average sound insulation between rooms in separate buildings is to be at least 49 dB, while at the range of frequencies between 100 and 3150 cycles/second sound insulation must not fall below the specified levels by more than 1 dB at any frequency in the range. Between terrace, semi-detached and similar layouts of dwellings, a higher level of sound insulation (52 dB) is required. There are certain provisions relating to flanking sound transmission, etc. Two grades of separating walls are specified, the higher grade for terrace housing and the like. The higher grade requires a separating wall to provide an average airborne sound reduction of at least 53 dB; the lower grade for dwellings in blocks of flats - 50 dB.

In both cases, there are specific levels at the range of frequencies between 100 and 3150 cycles/second. A number of 'deemed to satisfy' constructions for solid and cavity wall construction are listed. For separating floors between dwellings, are grade of airborne sound insulation is specified - at least 52 dB. Two 'deemed to satisfy' constructions are listed. The requirement for insulation against impact sound is again related to the same range of frequencies. There are five 'deemed to satisfy' floor constructions.

The Danish regulations differ from those current in the United Kingdom in that they specify minimum sound insulation figure for entrance doors separating the dwelling from a public lobby or staircase in blocks of flats. The level is set at 30 dB. As this has meant that manufacturers have had to modify the designs of their entrance doors which they were marketing, and also the designs of letter boxes. The requirements only came into effect from April 1969. Industry had, therefore, time to rearrange their production rams to meet the new requirement.

The regulations also specify that the reverberation in public staircases in blocks of flats should not exceed 1½ seconds at frequencies over 500 cycles/second.; also that the reverberation time in public (common) corridors and lobbies in blocks of flats shall not exceed 1 second.

These requirments mean in effect, that at least the whole ceiling area of the the stairwell and the undersides of all landings have to be covered with sound absorbant materials.

Finally, in the Danish regulations, there are requirements limiting the noise levels of installations and the mechanical equipment in residential buildings. These include such items as plumbing, water, storage cisterns, heating and ventilating plants, lifts and refrigerators. This requirement, which is a recent one, may well mean that some parts of conventional installations will have to be modified. Some will also have to be taken in the selection and mounting of mechanical equipment. The regulations originally required that service installations should not be fixed on separating walls between dwellings. They were, therefore, having to be fixed to internal walls of dwellings which are usually of lighter construction. Experience has shown that this practice was unsatisfactory from the standpoint of sound control. It was better to have the installations mounted on the heavier separating walls, provided the correct forms of mountings were used.

In Denmark, the National Building Research Institute (Statens Byggeforskiningsinstidnt) operates a mobile laboratory for the measurement of sound insulation, etc., in the field. One of the laboratory's recent responsibilities has been to assess the noise levels in dwellings resulting from the use of electric waste disposal units in kitchens; also the level of sound insulation provided by new design of entrance doors to flats.

SWEDEN

Sound insulation in buildings is controlled through the National Building Regulations (Svensk Byggnom 1967: SBN 67), and the authority of the Swedish Building Ordinance (Byggnadsstagyn 76:2) SBN 67: Chapter 34 (Lgudisolering) deals with sound insulation; Svensk Byggnorm Supplement S34:6 gives details of 'deemed to satisfy' examples of wall and floor constructions. The regulations the the supplement give considerable guidance on methods of assessment and measurement, as well as on the design and construction of buildings and constructional elements.

The measurement of airborne and impact sound insulation follows the requirements of the Swedish National Standard SIS 02 52 51: Measurement of Sound Insulation, which is in agreement with ISO/R 140 (1960). The standard is supplemented by information contained in the Swedish National Testing Establishment's Circulars No. 38 which give general guidance; No. 40 which deals with the measurement of noise levels in buildings; and No. 39 which deals with the measurement of sound absorption. Requirements for airborne and impact sound insulation in buildings are set out in tabulated form (Table 34-2) in regulations SBN 67. There are different requirements for separating walls and floors for terrace and semi-detached houses and for other types of dwellings, eg. flats, where there is a special requirement for impact sound insulation between a public staircase, or corridor, and a dwelling. There are separate requirements for hotels, institutional buildings, schools and office buildings. The following is a comparison between the requirements for airborne and impact sound insulation in blocks of flats with earlier Swedish requirements and the Danish, English and German requirements.

Country	Year	Definition	Wall between rooms[1] with floor area in m^2				Floor between rooms with floor area in m^2			
			10	15	20	25	10	15	20	25
Sweden	1950	D_{10}	50	51	51	52	50	52	53	54
Sweden	1960	D_{10}	52	53	53	54	52	54	54	56
Sweden[2]	1967	R'	52	52	52	52	53	53	53	53
Denmark[2]	1961-1968	$D_{0.5}$	53	52	51	51	53	53	53	53
Great Britain[3]	1960	$D_{0.5}$	52	51	50	50	52	52	52	52
Germany	1962	R'	52	52	52	52	52	52	52	52

[1] depth of the room = 1.5 x width

[2] in the Sound Insulation Committee of the Scandinavian Committee for Building Regulations (NKB); Norway has adopted the present Danish requirements, whilst Finland has adopted the Swedish proposal.

[3] for some conditions values 5 dB lower apply.

Table 4 Requirements for airborne sound insulation in blocks of flats, inde la db.

Table 5 Requirements for impact noise level in blocks of flats, index li dB.

Country	Year	Definition	Floors between rooms with floor area in m^2			
			10	15	20	25
Sweden	1950	L_{10}	66	66	66	66
Sweden	1960	L_{10}	63	63	63	63
Sweden[1]	1967	$L_{0.5}$	63	63	63	63
Denmark[1]	1961-1968	$L_{0.5}$	60	62	63	64
Great Britain[2]	1960	$L_{0.5}$	62	64	65	66
Germany[3]	1962	L_{10}	65	65	65	65

[1] see note (2) to Table 1.

[2] For some conditions values 6 dB higher apply.

[3] Two years after completion values 3 dB higher apply.

The new Swedish regulations SBN 67 have introduced requirements for maximum sound levels from such items as plumbing installations, ventilation ducts, etc. The regulations also set out in tabulated form (Table 34.3) maximum noise levels in dB (A) for habitable rooms and kitchens in dwellings, working areas in offices, hotel guestrooms, and school classrooms. In the regulations relating to the sound level of plumbing installations, a 5 dB stricter requirement has been introduced for drawing water from a sink or flushing wet pan that running water into a bath.

As in Denmark, there are requirements relating to maximum reverberation time in public staircases and corridors in blocks of flats, and corridors in hotels and nursing homes. In principle, the requirements mean that the underside of staircases and corridor ceilings have to be provided with a sound absorbant treatment.

THE NETHERLANDS

The sound insulation requirement of Netherlands model bylaws is based on the Dutch standard code of practice, NEN 1070 (1968) 'Noise Control and Sound Insulation in Dwellings.' This code, like BS code of practice CP3: Chapter III, deals both with principles and their application in design. Insulation against airborne and impact sound is discussed as well as the control of indirect sound transmission. Two grades of insulation are specified- moderate and good. The requirements of the Netherlands model bylaws relate to the moderate catagory as it was decided that, while more stringent requirements were desirable in the future, for the present time, the aim of regulation was to avoid serious noise nuisance rather than to insulate a dwelling completely from noise from an adjoining dwelling. A requirement which ensures the use of sound absorbent materials in common staircases in blocks of flats is a feature of the code.

GERMANY

The following refers to West Germany (Federal German Republic), though in many respects there are common features in the Germanic system of regulations generally including, to a degree, the Republic of Austria and DIR through the use of codes and industry standards. (DIN: Deutsch Normen). In Germany, where a least in the larger towns, most dwellings are in blocks of flats, proposals for the codification of sound insulation in buildings were made in 1938 for the first time.

In the 1950's, a new approach to the control of sound insulation was adopted to take into account field experience especially with newer froms of lightweight double walls. Einheitliche Mitteilung and Bewerhung Von Messergebrissen' (1953) introduced the concept of 'Schallschutzmass' in the form of single figure representing the sound insulation grading curves in place of the earlier arithmatical average figure.

There are differences in detail in building regulation between the different states (lands) of the Federal German Republic. However, the requirements of DIN 4109: 'Schallschutz im Hochban' (1962) serve as a general guide to sound insulation in buildings in Germany.

The standard is in five parts: General information; requirements; examples meeting the requirements; floating finishes for heavy floors; explanatory memoranda. The standard is supplemented by a more general standard dealing with the definition of acoustic terms DIN 1320: Allegemaine Benennuny in der Akustik.' Two standards deal with the measurement of sound insulation and sound absorption in buildings; DIN 52 210; 'Banakustische Prufungen; Bestimmungen des Schallabsorptions grades im Hallraum.'

FRANCE

The code deals with protection against sound coming from sources outside a dwelling. It specifies that the sound insulation between the main rooms of a dwelling and the exterior shall be at least 15 dB, 20 dB and 25 dB, for the low middle and high frequency bands. There are also requirements relating to insulation against airborne noise between dwellings-36/48/54 dB; between common corridors and habitable rooms or kitchens -30/38/38 dB: and between habitable rooms and lift shafts, etc, 34/45/51/ dB.

There are also requirements for insulation against impact noise sound.

The code also provides that noise from mechanical installations, etc, should be controlled so that the sound level in a bedroom is not more than 30 dB, or in a living room 35 dB. These figures relate to full furnished rooms and the code notes that the levels correspond to 35 dB (A) and 40 dB (A) in empty rooms. Finally the code requires that there should be arrangements in any building containing dwellings to prevent noises from industrial and commercial operations in that building, being a source of nuisance to residents.

In France, where requirements comprise both reduction factors for separating structures between dewlling measured traditionally in the laboratory and normalized figures of measurements made in completed buildings, average figures for airborne and impact sound are given for the frequency ranges 100 - 320, 400 - 1250, and 1600-3200 Hz. This is claimed to provide a simple situation without troublesome evaluations and does not pretend to be more knowledge than is available.

The central authority in France, responsible for building regulations, is the Ministry of Construction. Much of the background to the technical codes is provided by the Centre Scientifique et Technique du Bâtiment (CSTD) which is also the authority responsible for the French system of Agrement.

A List of Major National Codes and Regulations

1. United Kingdom
   a) The Building Standards (Scotland) Regulations 1963
      Statutory Instruments 1963, No. 1897, HMSO, London
      (Part VIII. Resistance to the transmission of sound, Table 12.
      Levels of sound insulation in houses, Schedule 9, Part VIII
      Resistance to the transmission of sound.)

b) The Building Regulations 1965 - Statuatory Instruments 1965, No. 1373 HMSO, London (Part G - Sound Insulation)

c) Building Research Digests - No. 96 - Sound Insulation and New Forms of Construction, No. 102 - Sound Insulation of Traditional Dwellings.(Requirements of building regulations - explanation of the grading system - sound insulation of party walls in traditional construction - sound transmission between rooms in the same dwelling - improvement of existing dwellings); No. 103 - Sound Insulation of Traditional Dwellings- 2 - Concrete floors, wood joist floors.

d) Department of Health for Scotland
Report of the Committee on Building Legislation in Scotland, HMSO, Edinburgh 1957.

2. Canada

a) National Building Code of Canada, 1968 - NRC No. 8305, National Research Council, Ottawa, Canada.

3. Denmark

a) Bygningsreglement forKobstaederne og Landet (Building Regulations for Urban and Rural Districts) Ministeriet Copenhagen 1966, Bol:g.

4. France

a) Regles administratives d'edification des locaux d'habitation, industriels at commerciaux de Montieur, Paris 1965.

5. Germany, Federal Republic

a) Frommhold and Hasenjager. Wohnungsban Norman (10 edit. 1967) Werner-Verlag - Dusseldorf (collection of DIN relating to housing includes DLN 4109: Sound Insulation)