Controlling sound transmission into buildings

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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20375534
Building Practice Note, 1985-09-01

CONTROLLING SOUND TRANSMISSION INTO BUILDINGS

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BPN 56
ISSN 0701-5216
Ottawa, September 1985

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ABSTRACT

This paper presents a procedure for calculating appropriate STC ratings for windows and other building envelope components to provide a required noise reduction. A reverse procedure to determine noise reduction by a given set of components, and their relative contributions to the transmitted noise, is also given. Both a worksheet method and an equivalent computer program are included.

RÉSUMÉ

Cette étude présente les calculs des valeurs de transmittance acoustique des fenêtres et des autres éléments des enveloppes de bâtiment nécessaires pour parvenir à l'isolation acoustique exigée. Elle indique également une méthode de calcul de l'isolation acoustique fournie par une série d'éléments et tenant compte de leur contribution relative. La méthode de calcul est présentée sous forme de feuillets à remplir et sous forme d'un programme d'ordinateur.

INTRODUCTION

The most pervasive urban noise source is road traffic, but other sources such as aircraft and industry often present problems. Intrusion of the outdoor noise into buildings interferes with many activities; conversation is the most obvious, but others ranging from sleep to concentrated thinking may also be affected. This activity interference can be controlled by proper design and construction of the building's exterior envelope.

This paper presents a method for selecting appropriate walls, windows, and other components to satisfy an indoor noise criterion at a site where the outdoor sound level has been determined. The first step in this procedure is to establish how much noise reduction must be provided by the building envelope. This value is then adjusted to allow for characteristics of the noise source and the building components (such as windows), to arrive at appropriate requirements for each component. Several detailed examples are given at the end of the text to illustrate both the basic design procedure, and the reverse calculation to determine noise reduction by a given set of components and their relative contributions to the reduction of transmitted noise. The reverse procedure is obviously most useful for assessing proposed modifications to an existing design.

Noise is described here in terms of the A-weighted sound level because of its near-universal use as a descriptor for environmental noise. (The concept of A-weighted sound levels and most of the other technical terms used here have been discussed in Canadian Building Digest 236 [1]. Current environmental regulations and guidelines usually specify the equivalent sound level (often denoted by L_{eq}). This is a measure of long-term average noise in dB(A). Use of the equivalent sound level has been validated by many social surveys. Although it is apparently the best single predictor of annoyance due to noise, the equivalent level seems to underestimate the importance of strong noise peaks. Thus very conservative indoor noise limits are strongly recommended when using this design procedure in applications where intermittent very loud noises are expected, such as very near to a truck route or an airport flight path.

In North America the most widely used rating for the sound insulation of building components such as walls or windows is the sound transmission class (STC). Specifying that all components should have STC ratings equal to the desired difference between outdoor and indoor noise levels provides a gross first approximation to the required noise reduction, but ignores some important factors. These are detailed below, in the course of presenting a straightforward five-step procedure for determining suitable STC values for the components of the exterior envelope.

REQUIRED NOISE REDUCTION

The required noise reduction (NR) is simply the difference between the outdoor sound level and the desired indoor sound level. As noted above, it is assumed that these are A-weighted equivalent sound levels (in dB(A)).

OUTDOOR SOUND LEVEL – INDOOR SOUND LEVEL = NOISE REDUCTION

Because of the wave nature of sound, the sound levels near an exterior surface (or inside a room) vary considerably. Some additional details are needed to specify fully what is meant by the "outdoor sound level" and the "indoor sound level".

Outdoor Sound Level

The outdoor sound level is the value that would be observed near the outside surface of the building. This includes both sound energy coming directly from the noise source and sound energy reflected from the building. For typical cases, this may be readily taken into account as follows:

a. In the case of an existing building, the equivalent sound level could be measured near the exterior surface; a distance of 2 m from the facade is specified in applicable standards. This would normally require the services of a competent consultant.

b. For the noise from road and railway traffic, simple procedures are available for predicting the A-weighted equivalent (preferably long-term average) sound levels at a building site. The procedure explained in the CMHC publication "Road and Rail Noise: Effects on Housing" [2] is among the simplest and most accurate of these. Such calculations predict the "free-field" sound level, with no allowance for sound energy reflected from the building surface. With this design procedure, three decibels should be added to the predicted outdoor sound level to allow for the effect of reflections from the building.

c. For aircraft noise, contour maps showing the noise exposure forecast (NEF) are available for the regions surrounding most airports in Canada. The A-weighted equivalent outdoor sound level for this design procedure (including a 3 dB correction for the effect of reflections) is approximately equal to 34 + NEF.

d. If measurements at the site (prior to construction) are to be used, the designer should be aware that sound levels several stories above ground level tend to be substantially higher than those near the ground, due to the effect of soft ground surfaces and intervening obstructions. Measured sound levels can be corrected using calculations such as those in Ref. 2 to predict the noise arriving at other positions. As in case b, above, three decibels should be added to the measured or predicted value to allow for the effect of reflections from the building. It is not uncommon for a room to have several exterior surfaces with different noise exposures. This design procedure can readily allow for this situation, as illustrated in the fourth example.

Indoor Sound Level

The maximum acceptable indoor sound level depends on the use of the room, and slightly different criteria have been proposed by various Canadian authorities. Similar limits are used for most common types of environmental noise. The range of values proposed for maximum acceptable indoor noise levels is given in Table 1 for a variety of residential and commercial uses. To ensure occupant satisfaction, use of the lowest value in each range is recommended.

Table 1 Range of maximum acceptable indoor noise levels proposed by various authorities. Values in the table are long term average (equivalent) sound levels.

Room Use	Maximum Indoor Noise Levels (dB(A))
Hospital or residential bedroom	30 to 40
Residential living, dining areas	35 to 45
Residential kitchen, bathroom	40 to 45
Conference room	35 to 45
Private office	40 to 45
General office areas, retail stores	45 to 50

The substantial increase in sound level near an open window is a matter of common experience, but even with closed windows the sound levels vary noticeably within a typical room. Normally the average sound level in the room is used as the "indoor sound level". Because sound levels tend to be highest near the exterior surfaces, it would be more prudent to consider a single work area adjacent to the outside wall of very large rooms such as open plan offices, as illustrated in Example 3.

CORRECTION FOR SOURCE GEOMETRY

The STC rating is calculated from laboratory measurements of sound transmission through a partition separating two hard-surfaced rooms. In these tests, sound waves striking the partition come from all angles — a condition described technically as "random incidence". By contrast, sometimes the sound waves striking a building facade come from only a narrow range of angles. Dependence of the noise reduction on the angle at which sound strikes the surface is quite complicated, but in general the noise reduction is lower when sound waves arrive nearly parallel to the surface. For a wall at right angles to a major roadway, or directly under an aircraft approach path, this effect may significantly diminish the noise reduction provided by a facade.

The examples following the text demonstrate the use of Table 2 to make approximate corrections for this effect. By convention, the angle is measured relative to perpendicular at the middle of the surface; thus sound coming from directly in front of the surface is at an angle of 0 degrees, whereas sound arriving parallel to the surface is at 90 degrees.

Table 2 Correction for source geometry (to be added to desired Noise Reduction to obtain required STC). The angular range best describing the dominant noise source should be used.

Angles at which sound arrives (0 = perpendicular to surface)	Correction
60 to 90 degrees	3
40 to 90 degrees	2
30 to 90 degrees	1
0 to 90 degrees	0

CORRECTION FOR MULTIPLE COMPONENTS

In most cases, several components (walls, windows, doors or roof) contribute significantly to the sound transmitted into a room. The simplest design approach is to require the same STC for all components, but this does not permit a designer to take advantage of the fact that many common wall and roof constructions have much higher STC ratings than typical windows or doors.

Normally, the designer's concern is the average sound level inside the room — the path by which the sound energy enters the room is not significant. Thus individual components may have different STC values, and only the combined performance of all the components must be fixed by the required noise reduction.

For each component, its STC indicates what fraction of the sound energy striking its surface is transmitted through the component. The sound energy flow through the component depends on both its STC and its surface area: the larger the surface, the more sound energy is transmitted. The overall noise reduction depends on the total sound energy transmitted by all the components. As illustrated by the examples, it is useful to consider first the division of the transmitted sound energy among the components, and next the detailed noise reduction for specific components (treated in subsequent sections).

A reasonable starting point for the calculation is to divide the transmitted sound energy equally among the components. This tends to allow lower STC values for windows or doors, because their area is usually only a small fraction of the exterior surface (as discussed in the following section on the effect of component area). In some cases it may be desirable to deviate from this suggested division of the transmitted sound energy. For example, if a particularly good wall were selected for non-acoustical reasons, the sound energy transmitted through other components could be increased.

The necessary correction to be added to the noise reduction is $-10 \log(P/100)$, where P is the percentage of the total sound energy entering the room that passes through the component. Table 3 presents these corrections in tabular form; use of this table to allow for distribution of the sound energy transmission among the components is demonstrated in the examples.

Table 3 Correction for sound transmission through multiple components (to be added to desired Noise Reduction to obtain required STC). The percentage of sound energy nearest to the tabulated values should be used. Percentages of the total energy greater than 100% are included as a mathematical convenience for the reverse calculation process illustrated in Example 2 and Worksheet 2.

Percentage of total sound energy transmitted by this component	Correction
200	−3
160	−2
125	−1
100	0
80	1
63	2
50	3
40	4
31	5
25	6
20	7
16	8
12	9
10	10
8	11
6	12
5	13

CORRECTION FOR COMPONENT AREA AND ROOM ABSORPTION

As noted above, the rate of sound energy flow through a component depends on its STC and surface area: the larger the surface, the more sound energy is transmitted. In addition, the noise reduction provided by the exterior surface depends on the balance between the rate of sound energy flow into the room and the rate of energy absorption by room furnishings such as carpets, heavy drapes, or upholstered furniture. For typical rooms, the total acoustic absorption due to room furnishings increases with room floor area. Thus if one considers sound transmission through a single component such as a window, the noise reduction varies in proportion to ratio of the window area to room floor area. Noise reduction may be increased by reducing the window size or by increasing the room size.

For moderately furnished rooms, the acoustical absorption varies only slightly with frequency, and the effect of room absorption may be determined with adequate precision if room floor area and a descriptive category ("hard", "intermediate", or "very absorptive") for room furnishings are specified. A bedroom with thick carpet, drapes, and upholstered furniture would be described as "very absorptive", as would an open plan office with an absorptive suspended ceiling and partial height screens. A typical kitchen or bathroom is "hard". Intermediate cases would include a carpeted dining room or a living room with minimal carpeting.

The corrections to be added to the noise reduction to allow for the effect of room absorption and component area may be calculated from the expression $10 \log(S/aF)$, where S is the component surface area and F is the room floor area. The value of a is 0.5, 0.8, or 1.25 for hard, intermediate, and very absorptive rooms, respectively. For ease of use (as shown in the examples below) these corrections are given in Table 4 for the typical range of component and floor areas.

Table 4 Correction for component area and room absorption (to be added to desired Noise Reduction to obtain required STC). Multiple elements such as identical windows may be considered as one component, and their combined area used as the component area.

Component area	Description of room furnishings		
(% of room floor area)	hard	intermediate	very absorptive
200	6	4	2
160	5	3	1
125	4	2	0
100	3	1	−1
80	2	0	−2
63	1	−1	−3
50	0	−2	−4
40	−1	−3	−5
31	−2	−4	−6
25	−3	−5	−7
20	−4	−6	−8
16	−5	−7	−9
13	−6	−8	−10
10	−7	−9	−11
8	−8	−10	−12
6	−9	−11	−13
5	−10	−12	−14

CORRECTION FOR SOURCE SPECTRUM

The STC was originally developed for rating airborne sound reduction by internal floors and partitions with sources such as the human voice, whose dominant sound energy is in the middle and high frequency ranges. STC does not properly rate insulation against noise sources with strong low frequency components. Because of this, the standard defining the STC specifically recommends against its use in applications involving the exterior walls of buildings.

The A-weighted sound level (like human hearing, which it approximates) has sharply reduced sensitivity to low frequency and very high frequency sounds. In passing from outdoors to indoors, the character of the sound is altered, because noise reduction by typical building components is smaller at low frequencies. Thus for example, the shrill high frequency whistle dominating the perceived outdoor loudness of noise from a nearby aircraft may be inaudible indoors, even though the low frequency roar is only slightly reduced. In general, the stronger the low frequency part of the outdoor noise, the smaller the reduction in A-weighted sound level provided by a given facade. The exact difference depends on the frequency dependence of both the outdoor sound and the sound transmission through the specific facade.

By identifying categories for common outdoor noise sources and building components, the effect of source spectrum on the reduction in the A-weighted noise can be estimated. The categories of building components are determined primarily by air leakage and by vibration isolation between the surfaces of the component. Sound transmission through cracks has little dependence on frequency; thus, for example, openable windows exhibit a smaller increase of noise reduction with increasing frequency than do sealed windows. On the other hand, double glazing exhibits stronger dependence on frequency than does single glazing because of the effect of the air cavity on vibration transfer from one surface to the other.

The following examples demonstrate use of the corrections given in Table 5. These corrections were calculated for the six source spectra in Figure 1, which are associated with typical transportation noise sources. For industrial sources, or other cases not specifically mentioned, the most similar spectral case should be used. Fitting building components into categories, and specifying "typical" frequency dependence for the noise from the specific transportation noise sources, involves some approximations. The corrections given in Table 5 are average values for each category. The variation within each category is generally comparable to the differences between categories, but the errors due to using these average values are minor relative to the systematic effects involved, and insignificant for human evaluation of the loudness of the noise.

Table 5 Correction for frequency dependence of the outdoor noise and component sound transmission (to be added to desired Noise Reduction to obtain the required STC). Source spectrum categories* are identified in Fig. 1; for noise from industry or other special cases, the most similar spectrum should be used.

		Noise source spectrum (see Fig. 1)					
	Building Component	A	B	C	D	E	F
a.	Single exterior door	−1	0	0	1	1	1
b.	Double exterior door, or single-glazed window, or openable thin window	0	1	2	2	3	3
c.	Sealed thin window, or openable thick window	0	1	3	4	6	6
d.	Sealed thick window, or exterior wall, or roof/ceiling	0	2	5	7	9	10

*The categories for building components depend on the typical frequency dependence of their sound transmission. Addition of a storm door with good weatherstripping converts a "single" door to a "double" door (category b). A "thin" window could have double or triple glazing with the total air space between the panes not exceeding 25 mm; such windows would fall in category b or c, for openable or sealed windows, respectively. For a "thick" window the total air space between panes exceeds 25 mm. If the interpane space is not uniform (as in the case of a double hung window with an added storm window), the average spacing should be used to differentiate between "thick" and "thin" windows.

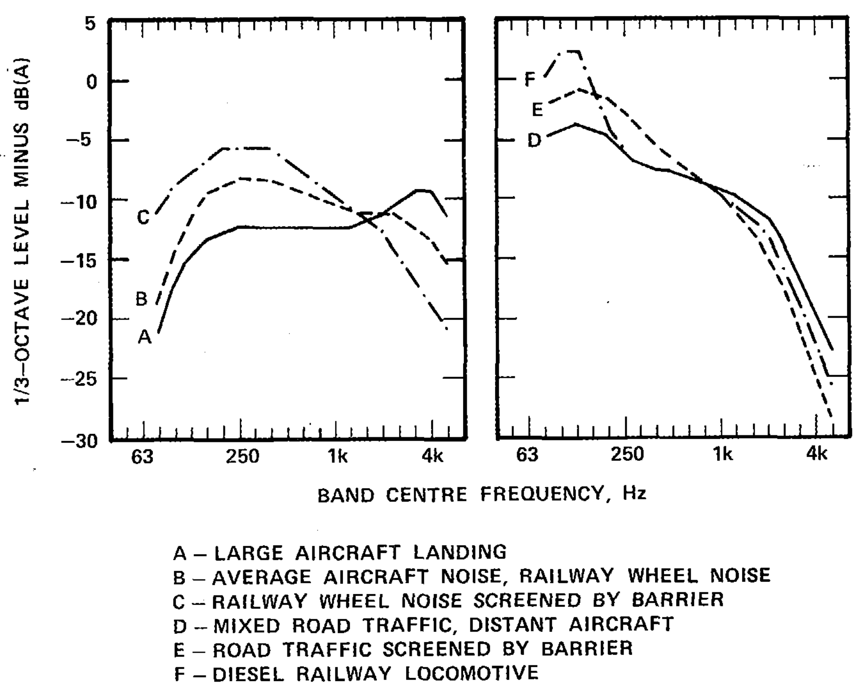


FIGURE 1 Representative spectra for some common noise sources.

EXAMPLE 1 Calculating required STC of components using Worksheet 1.

An indoor sound level of 35 dB(A) is required in the bedroom of an apartment facing a major highway. The predicted sound level at the site is 69 dB(A) (allowing for reflection from the building; the outdoor sound level is 72 dB(A)). The floor area of the bedroom is 5 × 4 m and carpeted. The exterior surface includes a 1 × 1.5 m window plus 10.5 m^2 of exterial wall. Find the required STC for the wall and window.

1. Outdoor sound level 72 dB(A)
   Indoor sound level 35 dB(A)
   Subtracting gives required Noise Reduction 37 dB
2. Sound comes from 0 to 90° angle — Correction from Table 2 0 dB
   Sum 37 dB

Component: Wall — After step 2 37 dB

3. Transmits 50 % of total sound energy. — From Table 3 3 dB
4. Component area 10·5 m^2; Room floor area 20 m^2 → 52·5 % of floor area
   Room absorption category very absorptive — From Table 4 -4 dB
5. Noise spectrum type D (select from Fig. 1)
   Component category d (see Table 5 caption) — From Table 5 7 dB

Required STC 43

Component: Window — After step 2 37 dB

3. Transmits 50 % of total sound energy. — From Table 3 3 dB
4. Component area 1·5; Room floor area 20 → 7·5 % of floor area
   Room absorption category very absorptive — From Table 4 -12 dB
5. Noise spectrum type D (select from Fig. 1)
   Component category c (see Table 5 caption) — From Table 5 4 dB

Required STC 32

If a brick veneer wall with STC = 56 were chosen for aesthetic reasons, the calculation could be adjusted to take advantage of this. Worksheet 1(b) can be used for this process. Because the calculation in Worksheet 1(b) proceeds from STC to noise reduction (i.e. – reverse), the corrections must be subtracted at Steps 3 and 4.

Component: Brick wall		STC is 56
3. Noise spectrum type D (select from Fig. 1) Component category d (see Table 5 caption)	From Table 5 7 dB	Correction -7 dB
4. Component area 10·5 Room floor area 20 → 52·5 % of floor area Room absorption category very absorptive	From Table 4 -4 dB	Correction +4 dB
5. Noise reduction if only this component transmits sound energy		53 dB
6. Required noise reduction (after Step 2)		37 dB
7. To obtain appropriate correction from Table 3, subtract Corresponding case in Table 3 is 5 % of total transmitted sound energy.		16

The values for the corrections from Table 4 and Table 5 for the wall are unchanged – selecting a higher STC simply reduces the percentage of the total transmitted sound energy that passes through the wall. In this case the correction falls out of the range given in Table 3, so the last listed value (5%) is used. If only 5% of the sound energy is transmitted through the wall, the calculation for the window may be adjusted as follows:

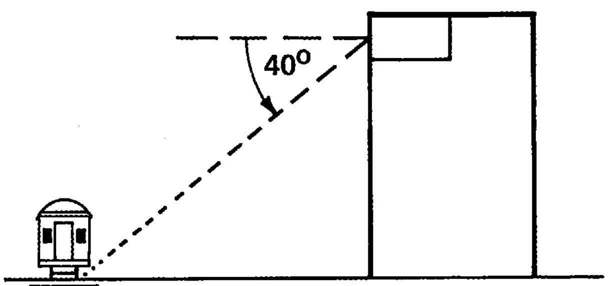
Component: Window	After step 2 37 dB
3. Transmits 95 % of total sound energy.	From Table 3 0 dB
4. Component area 1·5 Room floor area 20 → 7·5 % of floor area Room absorption category very absorptive	From Table 4 -12 dB
5. Noise spectrum type D (select from Fig. 1) Component category c (see Table 5 caption)	From Table 5 4 dB
	Required STC 29

The change (from 3 to 0) in the correction from Table 3 for the window gives a reduction in the required STC from 32 to 29.

EXAMPLE 2 Reverse calculation procedure to determine the noise reduction by a facade composed of elements with specified STC. Demonstrates use of Worksheet 2.

Calculate the reduction of noise from an adjacent electric railway, for a room with intermediate absorption and floor area of 12 m^2. The exterior surface has three components:

Wall (STC = 40, area = 10 m^2);
Window (STC = 26, area = 4 m^2, thin double glazing);
Door (STC = 22, area = 2.5 m^2, no storm door).



This room is assumed to be in a high-rise building near the track so the sound arrives at the surface from an angular range of 40 to 90 degrees.

When using Worksheet 2, values from the tables must be subtracted at steps 1, 2 and 5 because the calculation is proceeding from STC to Noise Reduction (i.e. – in reverse). At step 4, where Table 3 is used in a special way to combine the sound energy contributions, the value from the table is used directly.

Component: Wall — STC is 40

1. Noise spectrum type B (select from Fig. 1); Component category d (see Table 5 caption) → From Table 5: 2 dB; Correction: -2 dB
2. Component area 10; Room floor area 12 → 83 % of floor area; Room absorption category intermediate → From Table 4: 0 dB; Correction: 0 dB
3. Noise reduction if only this component transmits sound energy: 38 dB

Component: Window — STC is 26

1. Noise spectrum type B (select from Fig. 1); Component category b (see Table 5 caption) → From Table 5: 1 dB; Correction: -1 dB
2. Component area 4; Room floor area 12 → 33 % of floor area; Room absorption category intermediate → From Table 4: -4 dB; Correction: +4 dB
3. Noise reduction if only this component transmits sound energy: 29 dB

EXAMPLE 2 continued

Component: Door		STC is 22
1. Noise spectrum type B (select from Fig. 1) Component category a (see Table 5 caption)	From Table 5 0 dB	Correction 0 dB
2. Component area 2.5 Room floor area 12 — 21 % of floor area Room absorption category ______	From Table 4 -6 dB	Correction +6 dB
3. Noise reduction if only this component transmits sound energy		28 dB

4. To combine the effect of sound energy transmitted through all components, use the lowest value for component noise reduction (from step 3 above for each component) as a first estimate. Estimated NR 28 dB

Component	Component noise reduction minus estimated NR	Portion of estimated sound transmitted by component
wall	38-28 = 10 dB	From Table 3 10 %
window	29-28 = 1 dB	From Table 3 80 %
door	28-28 = 0 dB	From Table 3 100 %
	dB	From Table 3 %

Combined sound transmission (relative to estimate) is the sum 190 %

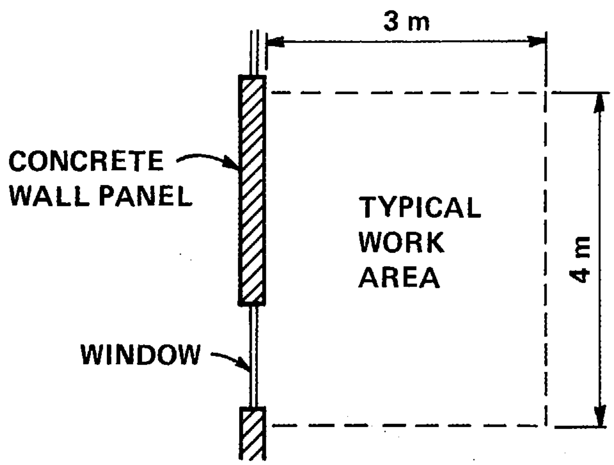
Corresponding correction from Table 3 -3 dB

5. Sound comes from 40 to 90° angle (From Table 2 2 dB). Correction -2 dB
6. Combined noise reduction by all components is given by the sum 23 dB

If one were interested in improving the noise reduction by this facade, both the door and the window would have to be changed to make a substantial difference.

EXAMPLE 3 Reverse calculation procedure for very large spaces.

In any room, the sound level near the exterior surface tends to be higher than the average sound level; this difference is important for large, very absorptive spaces such as open-plan offices. In such rooms, the exterior envelope should be designed to give appropriate noise levels in the work areas immediately adjacent to the exterior surface as shown below.



The room's exterior surface has windows (1 m wide × 2.5 m high) alternating with wall panels (3 m wide × 2.5 m high) as shown at the left. The room is to be used as an open-plan office and has an absorptive suspended ceiling and many absorptive room divider screens. Each work space has floor area of 12 m^2 and the adjacent surface includes: Window with area = 2.5 m^2, STC = 32, double glass whose interpane airspace is 12 mm. The windows are not openable. Wall with area = 7.5 m^2, STC = 53.

If the traffic noise measured outside (near the wall) is 74 dB(A), calculate the resulting noise in a work area adjacent to this surface.

This example illustrates the use of Worksheet 2. When using this worksheet, values from the tables must be subtracted at steps 1, 2 and 5 because the calculation is proceeding from STC to noise reduction (i.e. – in reverse). At step 4, where Table 3 is used in a special way to combine the sound energy transmitted through all components, the value from the table is used directly.

Component: Wall — STC is 53

1. Noise spectrum type D (select from Fig. 1); Component category d (see Table 5 caption) — From Table 5: 7 dB; Correction: -7 dB
2. Component area 7.5 m^2; Room floor area 12 m^2 — 63 % of floor area; Room absorption category: very absorptive — From Table 4: -3 dB; Correction: +3 dB
3. Noise reduction if only this component transmits sound energy: 49 dB

Component: Window — STC is 32

1. Noise spectrum type D (select from Fig. 1); Component category c (see Table 5 caption) — From Table 5: 4 dB; Correction: -4 dB
2. Component area 2.5; Room floor area 12 — 21 % of floor area; Room absorption category: very absorptive — From Table 4: -8 dB; Correction: +8 dB
3. Noise reduction if only this component transmits sound energy: 36 dB

EXAMPLE 3 continued

4. To combine the effect of sound energy transmitted through all components, use the lowest value for component noise reduction (from step 3 above for each component) as a first estimate. Estimated NR 36 dB

Component	Component noise reduction minus estimated NR		Portion of estimated sound transmitted by component
Wall	49-36 = 13	dB	From Table 3 5 %
Window	36-36 = 0	dB	From Table 3 100 %
		dB	From Table 3 %
		dB	From Table 3 %

Combined sound transmission (relative to estimate) is the sum 105 %

Corresponding correction from Table 3 0 dB

5. Sound comes from 0 to 90° angle (From Table 2 0 dB). Correction 0 dB
6. Combined noise reduction by all components is given by the sum 36 dB

For the outdoor noise level of 74 dB(A), this reduction would result in an indoor traffic noise level of 74 − 36 = 38 dB(A), which would generally be considered acceptable in an office environment. In this example most of the sound energy is transmitted through the window – a very common situation. The indoor sound level of 38 dB(A) is an "average" value – the sound level would be noticeably higher near the window, and this should be considered in detailed arrangement of the workspace.

For enclosed offices, essentially the same procedure could be used (except that the category for room absorption would normally be "intermediate" or "hard" depending on the type of ceiling and furnishings).

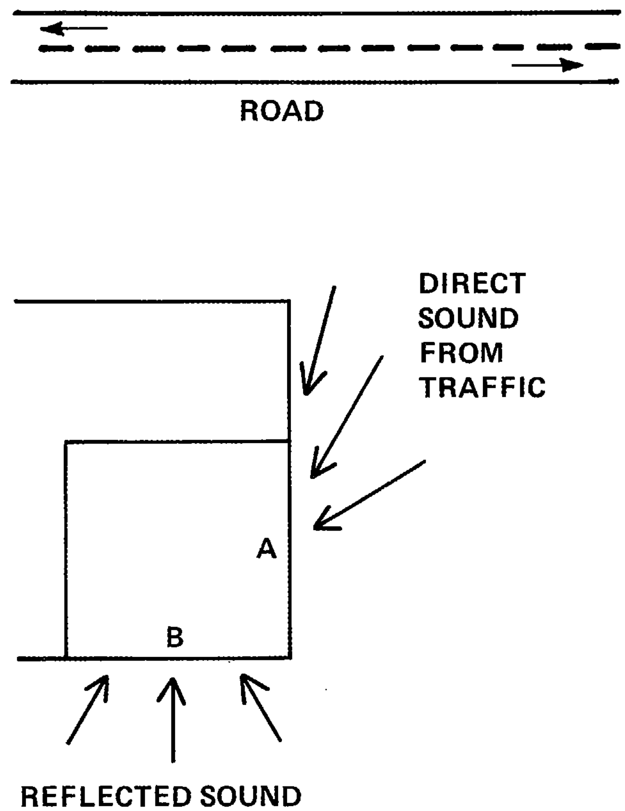
An indoor noise level in this range may be annoying if there are strong noise peaks, or other characteristics which draw attention to the noise.

EXAMPLE 4 Calculating the required STC of components when a room has exterior surfaces with different noise exposures.

In many cases a building has one or more exterior surfaces which are not directly exposed to the noise source. For the room shown in the sketch, surface A has an outdoor sound level of 77 dB(A) from the highway, but surface B has an outdoor level of only 65 dB(A) (caused by reflected sound from the next row of buildings). The room has "intermediate" absorption and its floor area is 25 m². The room's exterior components are:

Surface A
wall (area = 12 m²)

Surface B
wall (area = 10 m²)
window (area = 3 m², openable double-glazed with 13 mm space).



This calculation makes use of Worksheet 1, as in Example 1, but the value for adjusted noise reduction (after Step 2) for each component is that for the appropriate surface.

For Surface A

1. Outdoor sound level 77 dB(A)
   Indoor sound level 35 dB(A)

   Subtracting gives required Noise Reduction 42 dB
2. Sound comes from 0 to 90° angle — Correction from Table 2 0 dB

   Sum 42 dB

For Surface B

1. Outdoor sound level 65 dB(A)
   Indoor sound level 35 dB(A)

   Subtracting gives required Noise Reduction 30 dB
2. Sound comes from 0 to 90° angle — Correction from Table 2 0 dB

   Sum 30 dB

EXAMPLE 4 (Continued)

Initially, assume that the transmitted sound is divided equally among the three components, i.e., 33% each.

Component: Wall (Surface A) — After step 2 42 dB ← Value for Surface A

3. Transmits 33 % of total sound energy. — From Table 3 5 dB
4. Component area 12 / Room floor area 25 → 48 % of floor area; Room absorption category intermediate — From Table 4 -2 dB
5. Noise spectrum type D (select from Fig. 1); Component category d (see Table 5 caption) — From Table 5 7 dB

Required STC 52

Component: Wall (Surface B) — After step 2 30 dB ← use value for Surface B

3. Transmits 33 % of total sound energy. — From Table 3 5 dB
4. Component area 9 / Room floor area 25 → 36 % of floor area; Room absorption category intermediate — From Table 4 -3 dB
5. Noise spectrum type D (select from Fig. 1); Component category d (see Table 5 caption) — From Table 5 7 dB

Required STC 39

Component: Window (Surface B) — After step 2 30 dB ←

3. Transmits 33 % of total sound energy. — From Table 3 5 dB
4. Component area 3 / Room floor area 25 → 12 % of floor area; Room absorption category intermediate — From Table 4 -8 dB
5. Noise spectrum type D (select from Fig. 1); Component category b (see Table 5 caption) — From Table 5 2 dB

Required STC 29

If it were desired to use the same exterior wall construction for both surfaces, the requirements could be adjusted by changing the distribution of sound energy among the components. This process is demonstrated at the end of Example 1, but is much less tedious when using the computer program in Appendix B.

WORKSHEET 1 To calculate required STC for each component. Use of this worksheet is illustrated in Example 1. Special cases for the outdoor sound level are noted in Section 1.

1. Outdoor sound level ________dB(A)
   Indoor sound level ________dB(A)

Subtracting gives required Noise Reduction ________dB

2. Sound comes from ____________angle — Correction from Table 2 ________dB

Sum ________dB

Component: — After step 2 ________dB

3. Transmits ____________% of total sound energy. — From Table 3 ________dB
4. Component area ____________ } ________% of floor area
   Room floor area ____________
   Room absorption category ____________________ — From Table 4 ________dB
5. Noise spectrum type ________(select from Fig. 1)
   Component category ________(see Table 5 caption) — From Table 5 ________dB

Required STC ________

Component: — After step 2 ________dB

3. Transmits ____________% of total sound energy. — From Table 3 ________dB
4. Component area ____________ } ________% of floor area
   Room floor area ____________
   Room absorption category ____________________ — From Table 4 ________dB
5. Noise spectrum type ________(select from Fig. 1)
   Component category ________(see Table 5 caption) — From Table 5 ________dB

Required STC ________

Component: — After step 2 ________dB

3. Transmits ____________% of total sound energy. — From Table 3 ________dB
4. Component area ____________ } ________% of floor area
   Room floor area ____________
   Room absorption category ____________________ — From Table 4 ________dB
5. Noise spectrum type ________(select from Fig. 1)
   Component category ________(see Table 5 caption) — From Table 5 ________dB

Required STC ________

WORKSHEET 1(b) To evaluate % of total sound energy transmitted by a component whose STC is specified. Because this calculation is proceeding from STC to noise reduction (i.e.– reverse), the corrections must be subtracted at Steps 3 and 4.

Component:		STC is ______
3. Noise spectrum type ______(select from Fig. 1) Component category ______(see Table 5 caption)	From Table 5 ______dB	Correction ______dB
4. Component area ______ ÷ Room floor area ______ = ______% of floor area Room absorption category ______	From Table 4 ______dB	Correction ______dB
5. Noise reduction if only this component transmits sound energy		______dB
6. Required noise reduction (after Step 2)		______dB
7. To obtain appropriate correction from Table 3, subtract Corresponding case in Table 3 is ______% of total transmitted sound energy.		______

WORKSHEET 2 To calculate the noise reduction by a building envelope from the component STC ratings and other data. Values from the tables must be subtracted at steps 1, 2, and 5 because the calculation is proceeding from STC to noise reduction (i.e.–in reverse). Use of this worksheet is illustrated in Example 2.

Component:		STC is ______
1. Noise spectrum type ______(select from Fig. 1) Component category ______(see Table 5 caption)	From Table 5 ______dB	Correction ______dB
2. Component area ______ ⎤ ______% of floor area Room floor area ______ ⎦ Room absorption category ______	From Table 4 ______dB	Correction ______dB
3. Noise reduction if only this component transmits sound energy		______dB

Component:		STC is ______
1. Noise spectrum type ______(select from Fig. 1) Component category ______(see Table 5 caption)	From Table 5 ______dB	Correction ______dB
2. Component area ______ ⎤ ______% of floor area Room floor area ______ ⎦ Room absorption category ______	From Table 4 ______dB	Correction ______dB
3. Noise reduction if only this component transmits sound energy		______dB

4. To combine the effect of sound energy transmitted through all components, use the lowest value for component noise reduction (from step 3 above for each component) as a first estimate. Estimated NR ______dB

Component	Component noise reduction minus estimated NR	Portion of estimated sound transmitted by component
______	______dB	From Table 3 ______%
______	______dB	From Table 3 ______%
______	______dB	From Table 3 ______%
______	______dB	From Table 3 ______%

Combined sound transmission (relative to estimate) is the sum ______%

Corresponding correction from Table 3 ______dB

5. Sound comes from ______angle (From Table 2 ______dB).Correction ______dB

6. Combined noise reduction by all components is given by the sum ______dB

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APPENDIX A

COMPARISON WITH CMHC DESIGN PROCEDURES

Design procedures based on the Acoustic Insulation Factor (AIF) are used in the Canada Mortgage and Housing publications "New Housing and Airport Noise" [3] (NHA-5185) and "Road and Rail Noise: Effects on Housing" [2] (NHA-5156). Definition of the AIF and a discussion of the procedure for selecting appropriate building components were presented in references 4 and 5, and much of this was reproduced in appendices of the 1981 editions of the CMHC publications. The CMHC design procedures using the AIF could be described as limited special cases of the procedure given in this paper.

Although using the AIF shields a designer from some of the acoustical details, it does so at the expense of simplifying or ignoring corrections for some of the physical factors discussed in this paper. Also, suppliers of components such as windows – whose acoustical test data are normally in terms of the Sound Transmission Class (STC) – must determine the AIF ratings for their products. The latter problem has been eased by including conversion procedures in appendices of the CMHC publications, but the continuing use of STC ratings by provincial regulators complicates comparison of CMHC and provincial requirements. By contrast, the calculation procedure in this paper retains (or enhances) the acoustical considerations in the CMHC procedure, but uses the more widely accepted STC ratings.

To compare specific details, the CMHC procedures for insulation against aircraft or traffic noise are translated here into the terminology of this paper.

Aircraft Noise

1. Outdoor noise is specified in NHA-5185 in terms of the Noise Exposure Forecast (NEF). The outdoor A-weighted equivalent sound level, (including 3 dB correction for reflections from the building) is approximately 34 + NEF; the same outdoor level is used for all of the exterior surfaces. The indoor noise level criteria for NHA-5185 when expressed as A-weighted equivalent levels are approximately:

   31 dB(A) for bedrooms;

   36 dB(A) for living rooms, dining rooms, etc.;

   41 dB(A) for kitchens, bathrooms, hallways, etc.

2. For simplicity, the procedure does not consider the angular range from which sound arrives. In effect it assumes that sound always comes from the full 0–90 degree range. Thus the implicit correction from Table 2 is 0 dB.

3. The basic design procedure in NHA-5185 divides the transmitted sound energy equally among the components, but an appendix presents extensions to this procedure which are identical to the corrections using Table 3 in this paper.

4. The procedure in NHA-5185 assumes that all rooms have "intermediate" absorption characteristics. Because rooms such as kitchens and bathrooms are normally acoustically "hard", this design approach gives sound levels several decibels higher than the nominal 41 dB(A) criterion for such rooms. Except for that limitation, the allowance for component area and room absorption in NHA-5185 is identical to the use of Table 4 in this paper.

5. The AIF ratings for building components in the tables in NHA-5185 were calculated assuming a noise spectrum identical to spectrum B (average aircraft noise) in this paper. Thus the correction for frequency dependence of the noise source and component sound transmission is essentially equivalent to the use of Table 5, except that no allowance is made for the change in source spectrum balance that would be expected at sites where the aircraft are normally near landing or very distant.

Summary The procedure in this paper and that in NHA-5185 should give similar results for most cases. The differences are not much greater than the uncertainty in translating the noise criteria from NEF to dB(A), except in cases where some exterior surfaces are screened from the noise. The method presented here permits use of the widely accepted STC rating, and offers more flexibility in dealing with special cases.

Road and Railway Noise

1. Outdoor noise is calculated in NHA-5156 in terms of the A-weighted equivalent sound level reaching the building. This predicted outdoor sound level does not include any allowance for reflections from the building, so 3 dB must be added to these levels for the procedure in this paper. The indoor noise level criteria for NHA-5156 (which are expressed as A-weighted equivalent levels) are:

   35 dB(A) for bedrooms;

   40 dB(A) for living rooms, dining rooms, etc.;

   45 dB(A) for kitchens, bathrooms, hallways, etc.

2. For simplicity, the procedure does not allow for the angular range from which sound arrives. For cases where the angular range is limited because the receiver is far above the source, the calculation does compensate for the reduction in noise insulation by using only the horizontal distance to calculate the noise reaching the outside surface. However, there is no consideration of the horizontal extent of the noise source. Although the comparison with the procedure in this paper is not exact, essentially NHA-5156 treats the outdoor sound as if it arrived from the full 0–90 degree range. Thus the implicit correction from Table 2 is 0 dB.

3. The basic design procedure in NHA-5156 divides the transmitted sound energy equally among the components, but an appendix presents extensions to this procedure which are identical to the corrections using Table 3 in this paper. Both procedures can deal with situations where a room has several exterior surfaces with different noise exposures (as illustrated in Example 4).

4. The procedure in NHA-5156 assumes that all rooms have "intermediate" absorption characteristics. Because rooms such as kitchens and bathrooms are normally acoustically "hard", this design approach gives sound levels several decibels higher than the nominal 45 dB(A) criterion for such rooms. Except for that limitation, the allowance for component area and room absorption in NHA-5156 is identical to the use of Table 4 in this paper.

5. The AIF ratings for building components in the tables in NHA-5185 were calculated assuming a noise spectrum identical to spectrum B (average aircraft noise) in this paper. An additional correction of 2 dB is inserted in the calculation of required AIF for the building components (Table 6.1 in NHA-5156). Thus the correction for frequency dependence of the noise source and component sound transmission is 2 dB greater than values from Table 5 with source spectrum B. If the noise reduction is limited by transmission through an openable window (as is usually the case), this will give very similar results to the procedure in this paper for spectra C to F. The procedure in NHA-5156 tends to overestimate the noise reduction by walls and sealed windows, especially for railway locomotive noise.

Summary The procedure in this paper and that in NHA-5185 should give similar results for most cases. The method presented here offers more flexibility in dealing with special cases and permits use of the widely accepted STC rating.

APPENDIX B

COMPUTER PROGRAM FOR DESIGN PROCEDURE

All the calculations for the design procedure can be performed by the following computer program. It is written in Microsoft GWBASIC (essentially identical to "Advanced BASIC" for the IBM Personal Computer), but could be readily translated to work on most personal computers. The program code is heavily annotated and uses descriptive names for variables to assist in translation to other versions of BASIC. Extensions beyond the minimal ANSI BASIC instruction set are similar to those available on most common personal computers.

The program uses menus for data entry where possible, as illustrated in the screen format examples (surrounded by heavy outline) inserted in the program listing. The examples show each screen as it would appear before answering the last question with default values corresponding to Example 1 (first four screens) and Example 2 (last screen). For each part of the data entry process, the screen is initially cleared and each question (with its associated prompts including the default value) is added only after the previous question is answered. After presentation of the result summary, the data entry process can be repeated, with current values as the defaults, to make any desired changes.

```
10  '**************** EXTERIOR WALL SOUND TRANSMISSION ************************
20  COLOR 10 :KEY OFF          'sets bright lettering, softkeys off in GWBASIC
30  OPTION BASE 1                                    'start array indices from 1
40  DIM TABLE2(4),TABLE5(4,6),ABSORP(3)
50  FOR I=1 TO 4 :READ TABLE2(I) :NEXT I  'corrections for angle range of source
60  DATA 3,2,1,0
70  FOR I=1 TO 4 :FOR J=1 TO 6  :READ TABLE5(I,J)
80  NEXT J :NEXT I          'corrections for source spectrum
90  DATA -1,0,0,1,1,1
100 DATA 0,1,2,2,3,3
110 DATA 0,1,3,4,6,6
120 DATA 0,2,5,7,9,10
130 FOR I=1 TO 3 :READ ABSORP(I) :NEXT I    'absorption coefficient categories
140 DATA 0.5,0.8,1.25
150 '
160 DEF FNLOG10(X)=LOG(X)/LOG(10)  'defines FNLOG10() as logarithm to base 10
170 '
180 DIM TYPE(8),TYPE$(9),AREA(8),CHOICE(8),ENERGY(8),STC(8),EXPOSURE(8)
190 DIM CORR4(8),CORR5(8),ANGLE(3),ANGLE$(4),OUTDOOR(3)
200 FOR I=1 TO 8                              'initial values for component data
210   ENERGY(I)=0 :STC(I)=0 :NR(I)=0 :AREA(I)=0
220   CHOICE(I)=1 :EXPOSURE(I)=1 :TYPE(I)=1
230 NEXT I
240 FOR I=1 TO 3                       'for each exterior surface noise exposure
250   ANGLE(I)=4                              'angular range default
260   OUTDOOR(I)=0                     'outdoor sound level for this surface
270 NEXT I
280 FILE$=""
290 MAIN.CHOICE=1 :SPECTRUM=1 :ABSORPTYPE=1
300 COMPONENTS=1 :SURFACES=1
310 INDOOR.LEVEL=0 :FLOOR.AREA=0
320 '
330 CLS 'this statement clears the screen
340 PRINT "Sound Transmission through the Exterior Surfaces of a Building"
350 PRINT
360 PRINT "This program calculates either:"
370 PRINT "      1) Component STC required for a given noise reduction"
380 PRINT "      2) Noise reduction by components of specified STC"
390 PRINT
400 PRINT "Requests for data entry include an explanatory prompt,"
410 PRINT "followed by a default value in parentheses.  Responses are:"
420 PRINT "    - to accept the default value, press CR or NEW-LINE"
430 PRINT "    - to set a value, type the number followed by CR or NEW-LINE"
440 '
450 '
460 '*************************************************** START OF MAIN LOOP
470 LOCATE 20,1: PRINT STRING$(80,45) 'print row of minus signs
480 LOCATE 21,1:PRINT "Options : 1. Find/change required STC for components"
490 LOCATE 22,10:PRINT " 2. Calculate noise reduction by specified components"
500 LOCATE 23,10:PRINT " 3. Load or save result file (or STOP)"
510 LOCATE 23,50:PRINT "........Choose action ";
520 VALUE=MAIN.CHOICE :GOSUB 3890 :MAIN.CHOICE=VALUE      'input with default
530 ON MAIN.CHOICE GOTO 570, 1630, 2440   'branch to main menu choices
540 GOTO 470                           'if illegal choice then redisplay main menu
550 '
560 '
570 '********************** branches here if MAIN.CHOICE=1 (FIND COMPONENT STC)
580 CLS
590 LOCATE 1,1:PRINT "FIRST DESCRIBE THE OUTDOOR NOISE SOURCE "
600 GOSUB 2920                 'get no. of surfaces with different noise exposure
610 FOR SURFACE=1 TO SURFACES
620   SURFACE$="for surface "+STR$(SURFACE)+" "
630   IF SURFACES=1 THEN SURFACE$=""
640   LOCATE 7,1:PRINT "Outdoor sound level in dB(A): ";
```

```
650   LOCATE 6+SURFACE,30: PRINT SURFACE$;
660   VALUE=OUTDOOR(SURFACE) :GOSUB 3890 : OUTDOOR(SURFACE)=VALUE
670   GOSUB 3010                                    'get ANGLE(SURFACE)
680 NEXT SURFACE
690 GOSUB 3160                          ' get SPECTRUM, the column index in Table5
```

```
FIRST DESCRIBE THE OUTDOOR NOISE SOURCE !

Noise outside is : 1. same for all exterior surfaces
                   2. two different noise exposures
                   3. three different noise exposures ....Choose case [ 1 ]?

Outdoor sound level in dB(A):  [ 72 ]?



Sound arrives from angular range:
               1 .  60 to 90 degrees
               2 .  40 to 90 degrees
               3 .  30 to 90 degrees
               4 .   0 to 90 degrees   .... Nearest case [ 4 ]?

Noise spectrum category :
         1. jet aircraft landing
         2. average aircraft noise, or railway wheel noise
         3. railway wheel noise screened by a barrier
         4. mixed road traffic, or distant aircraft
         5. road traffic screened by a barrier
         6. diesel railway locomotives           .........Nearest case [ 4 ]?
```

```
700 CLS
710 LOCATE 1,1 :PRINT "NOW ENTER INFORMATION ABOUT THE ROOM "
720 LOCATE 3,1 :PRINT "Indoor sound level in dB(A) : ";
730 VALUE=INDOOR.LEVEL :GOSUB 3890 :INDOOR.LEVEL=VALUE
740 GOSUB 3280          'get FLOOR.AREA, room category ABSORPTYPE, COMPONENTS
```

```
NOW ENTER INFORMATION ABOUT THE ROOM !

Indoor sound level in dB(A) : [ 35 ]?

In your choice of units, give room floor area : [ 20 ]?

Category for room furnishings :
    1. hard (e.g.- kitchens, or bathrooms)
    2. intermediate (carpet or soft furniture)
    3. very absorptive (e.g.- carpeted bedroom)  ...... Nearest case [ 3 ]?

Exterior surface components include walls, windows, etc.
Number of components  [ 2 ]?
```

```
750 FOR COMP=1 TO COMPONENTS                            'get data for each component
760   CLS
770   LOCATE 1,1:PRINT "FOR COMPONENT ";COMP;
780   GOSUB 3610 'this gosub gets TYPE(COMP) and CORR5(SPECTRUM,TYPE(COMP))
790   IF SURFACES>1 THEN LOCATE 13,1 :PRINT "For this component ";
800   SURFAC=EXPOSURE(COMP) :GOSUB 3460 :EXPOSURE(COMP)=SURFAC 'which surface?
810   OUTDOOR.LEVEL=OUTDOOR(EXPOSURE(COMP))       'get the outdoor exposure
820   CORR2=TABLE2(ANGLE(EXPOSURE(COMP)))  'from Table 2 for angular range
830   NR(COMP)=OUTDOOR.LEVEL-INDOOR.LEVEL+CORR2    'needed Noise Reduction
840   LOCATE 18,1 :PRINT "In same units as floor area, give component area ";
850   VALUE=AREA(COMP) :GOSUB 3890 :AREA(COMP)=VALUE    'get area of component
860   CORR4(COMP)=10*FNLOG10(AREA(COMP)/(FLOOR.AREA*ABSORP(ABSORPTYPE)))
870   'value of CORR4() matches the correction from Table4 for component COMP
880   LOCATE 20,1 :PRINT "Calculation options : "
890   LOCATE 20,24 :PRINT "1. Default division of sound energy"
900   LOCATE 21,24 :PRINT "2. Set specific STC"
910   LOCATE 22,24 :PRINT "3. Set transmitted sound energy"
920   LOCATE 22,60 :PRINT ".... Choice  ";       'select calculation option
930   VALUE=CHOICE(COMP) :GOSUB 3890 :CHOICE(COMP)=VALUE
```

```
FOR COMPONENT  1

Component type: 1.  Single Exterior Door
                2.  Double Exterior Door
                3.  Window, single glazed
                4.  Window, openable thin  double or triple
                5.  Window, sealed  thin   double or triple
                6.  Window, openable thick double or triple
                7.  Window, sealed  thick   double glazed
                8.  Exterior wall
                9.  Roof / ceiling          .............. Nearest case [ 8 ]?




In same units as floor area, give component area [ 10.5 ]?

Calculation options :  1. Accept default STC
                       2. Set specific STC
                       3. Set transmitted sound energy     .... Choice [ 1 ]?
```

```
940   ON CHOICE(COMP)  GOTO 1100,960,1020        'and proceed accordingly
950   GOTO 920  'if illegal choice
960   LOCATE 23,1            'branches here if CHOICE(COMP)=2 to set the STC
970     PRINT "Specific STC value              " :LOCATE 23,20
980     VALUE=STC(COMP) : GOSUB 3890 : STC(COMP)=VALUE
990     X=NR(COMP)-STC(COMP)
1000    ENERGY(COMP)=100*10^((X+CORR4(COMP)+CORR5(COMP))/10)
1010    GOTO 1050
1020  LOCATE 23,1            'branches here if CHOICE(COMP)=3 to set energy %
1030    PRINT "Percentage of total sound energy               ":LOCATE 23,34
1040    VALUE=ENERGY(COMP) :GOSUB 3890 : ENERGY(COMP)=VALUE
1050    IF ENERGY(COMP)<100 THEN GOTO 1100   'proceed if ENERGY() under 100%
1060    LOCATE 24,1 :PRINT "This choice transmits";    'if over 100%
1070    PRINT USING "#####";ENERGY(COMP);
1080    PRINT " % of total sound energy";
1090    GOTO 920                              'loop back if over 100%
1100 NEXT COMP
```

```
1110 'Now divide up the remaining sound energy among other components
1120 PORTIONS=0 :FIXED.ENERGY=0
1130 FOR COMP=1 TO COMPONENTS
1140   IF CHOICE(COMP)=1 THEN PORTIONS=PORTIONS+1
1150   IF CHOICE(COMP)=2 THEN FIXED.ENERGY=FIXED.ENERGY+ENERGY(COMP)
1160   IF CHOICE(COMP)=3 THEN FIXED.ENERGY=FIXED.ENERGY+ENERGY(COMP)
1170 NEXT COMP
1180 IF PORTIONS=0 THEN GOTO 1270 'if ENERGY(COMP) assigned for all components
1190 FOR COMP=1 TO COMPONENTS                    'allot the extra energy
1200   IF CHOICE(COMP)>1 THEN GOTO 1240  'only interested in default STC cases
1210   ENERGY(COMP)=(100-FIXED.ENERGY)/PORTIONS
1220   X=NR(COMP)+CORR4(COMP)+CORR5(COMP)
1230   STC(COMP)=X-10*FNLOG10(ENERGY(COMP)/100)
1240 NEXT COMP
1250 '
1260 CLS                'clear screen and print out summary
1270 LOCATE 1,1 :PRINT "Indoor  sound level in dB(A) is ";INDOOR.LEVEL
1280 LOCATE 2,1 :PRINT "Room absorption category is ";ROOM$
1290 LOCATE 3,1 :PRINT "Outdoor sound level is ";
1300 FOR SURFACE=1 TO SURFACES
1310   ON SURFACES GOTO 1320,1360,1360
1320   LOCATE 3,24        'if only one surface
1330     PRINT USING "###";OUTDOOR(SURFACE); :PRINT "dB(A) (plus";
1340     PRINT TABLE2(ANGLE(SURFACE));"dB from Table 2)"
1350     GOTO 1400
1360   LOCATE 2+SURFACE,24      'if more than 1 surface
1370     PRINT USING "###";OUTDOOR(SURFACE); :PRINT " dB(A) (plus ";
1380     PRINT USING "#"; TABLE2(ANGLE(SURFACE));
1390     PRINT " dB from Table 2) for surface ";SURFACE
1400 NEXT SURFACE
1410 LOCATE 7,26                                   'now print table heading
1420 PRINT " After   From Table3   From Table4   From Table5   STC"
1430 LOCATE 8,1 :PRINT "Components:"
1440 LOCATE 8,26 :PRINT "Step 2   (% energy)   (% floor area)  (spectrum)"
1450 X$=STRING$(55,45) :LOCATE 9,26 : PRINT X$             'draw a line across
1460 '
1470 FOR COMP=1 TO COMPONENTS                   'print each line of table
1480   CORR3(COMP)=-10*FNLOG10(ENERGY(COMP)/100)
1490   LOCATE COMP+9,1 :PRINT USING "#.";COMP;
```

```
Indoor  sound level in dB(A) is  35
Room absorption category is high absorption
Outdoor sound level is  72 dB(A) (plus 0 dB from Table 2)



                          After   From Table3   From Table4   From Table5   STC
Components:              Step 2   (% energy)   (% floor area)  (spectrum)
                         -------------------------------------------------------
1.  Exterior wall           37    3 dB ( 50 %)   -4 dB ( 53 %)     7 dB      43
2.  Window, openable thick  37    3 dB ( 50 %)  -12 dB (  8 %)     4 dB      32








-------------------------------------------------------------------------------
Options : 1. Find/change required STC for components
          2. Calculate noise reduction by specified components
          3. Load or save result file (or STOP)  ........Choose action [ 1 ]?
```

```
1500   PRINT USING "\                      \";TYPE$(TYPE(COMP));
1510   PRINT USING "###   "; NR(COMP);
1520   PRINT USING "+##"; CORR3(COMP); :PRINT "dB (";
1530   PRINT USING "###";ENERGY(COMP); :PRINT "%)   ";
1540   PRINT USING "+##";CORR4(COMP); :PRINT "dB (";
1550   AREA.PERCENT=100*AREA(COMP)/FLOOR.AREA
1560   PRINT USING "###";AREA.PERCENT; :PRINT "%)     ";
1570   PRINT USING "+##";CORR5(COMP); :PRINT "dB       ";
1580   PRINT USING "###";STC(COMP)
1590 NEXT COMP
1600 GOTO 470                                 'returns to main menu after this
1610 '
1620 '
1630 '******************** branches here if MAIN.CHOICE=2 (FIND NOISE REDUCTION)
1640 CLS
1650 LOCATE 1,1 :PRINT "FIRST DESCRIBE THE OUTDOOR NOISE SOURCE "
1660 GOSUB 2920             'get no. of surfaces with different noise exposure
1670 FOR SURFACE=1 TO SURFACES
1680   SURFACE$="for surface "+STR$(SURFACE)+" "
1690   IF SURFACES=1 THEN SURFACE$=""
1700   LOCATE 7,1 :PRINT "Outdoor sound level in dB(A) "
1710   LOCATE 6+SURFACE,30 :PRINT SURFACE$;                     'identify surface
1720   VALUE=OUTDOOR(SURFACE) :GOSUB 3890 :OUTDOOR(SURFACE)=VALUE    'get level
1730   GOSUB 3010                     'get ANGLE(SURFACE), the index in Table 2
1740 NEXT SURFACE
1750 GOSUB 3160                     ' get SPECTRUM, the column index in Table5
1760 CLS
1770 LOCATE 1,1 :PRINT "GENERAL INFORMATION FOR THIS CALCULATION"
1780 LOCATE 3,1 :PRINT "Calculation is for ONE SURFACE ";
1790 SURFAC=1 :GOSUB 3460: SURFACE=SURFAC           'use surface 1 as default
1800 'now have desired index SURFACE; proceed for components on it
1810 GOSUB 3280            'get FLOOR.AREA, room category ABSORPTYPE, COMPONENTS
1820 FOR COMP=1 TO COMPONENTS                        'get data for each component
1830   CLS
1840   LOCATE 1,1 :PRINT "FOR COMPONENT ";COMP;
1850   GOSUB 3610                        'to get component category TYPE(COMP)
1860   'also gets CORR5(SPECTRUM )the correction from Table5
1870   IF SURFACES>1 THEN LOCATE 14,1 :PRINT "For this component";
1880   SURFAC=EXPOSURE(COMP) :GOSUB 3460 :EXPOSURE(COMP)=SURFAC
1890   IF EXPOSURE(COMP)<>SURFACE THEN GOTO 1980     'skip if on other surface
1900   LOCATE 18,1 :PRINT "In same units as floor area, give component area ";
1910   VALUE=AREA(COMP) :GOSUB 3890 :AREA(COMP)=VALUE
1920   CORR4(COMP)=10*FNLOG10(AREA(COMP)/(FLOOR.AREA*ABSORP(ABSORPTYPE)))
1930   'CORR4() is correction from Table4 for component area /absorption
1940   LOCATE 20,1 :PRINT "STC value for this component ";
1950   VALUE=STC(COMP) :GOSUB 3890 :STC(COMP)=VALUE  'get current STC value
1960   ATTEN=0                        'use Noise Reduction=0 as a trial value
1970   ENERGY(COMP)=100*10^((ATTEN+CORR4(COMP)+CORR5(COMP)-STC(COMP))/10)
1980 NEXT COMP
1990 CLS
2000 TOTAL.ENERGY=0             'combine the energy from relevant components
2010 FOR COMP=1 TO COMPONENTS
2020   IF EXPOSURE(COMP)<>SURFACE THEN GOTO 2040     'skip if on other surface
2030   TOTAL.ENERGY=TOTAL.ENERGY+ENERGY(COMP)          'energy % re ATTEN=0
2040 NEXT COMP
2050 ATTEN=-10*FNLOG10(TOTAL.ENERGY/100)
2060 FOR COMP=1 TO COMPONENTS                     'allot the extra energy
2070   IF EXPOSURE(COMP)<>SURFACE THEN GOTO 2090     'skip if on other surface
2080   ENERGY(COMP)=ENERGY(COMP)*10^(ATTEN/10)
2090 NEXT COMP
2100 ATTEN=ATTEN-TABLE2(ANGLE(SURFACE))      'correction for angular range
2110 '
2120 CLS :LOCATE  1,1 :PRINT "RESULT SUMMARY" :PRINT "Outside";
2130 IF SURFACES>1 THEN PRINT " surface ";SURFACE;        'if multiple surfaces
```

```
2140 PRINT " sound level is";
2150 PRINT USING "###";OUTDOOR(SURFACE); :PRINT " dB(A) from angle";
2160 PRINT USING "\                \"; ANGLE$(ANGLE(SURFACE))
2170 LOCATE 3,1 :PRINT "Room absorption category is ";ROOM$
2180 LOCATE 5,30 :PRINT "STC     From Table4    From Table5    Energy %"
2190 LOCATE 6,36 :PRINT "(% floor area)    (spectrum)"
2200 LOCATE 7,1 :PRINT "Components:"
2210 LOCATE 7,30 :PRINT "------------------------------------------------"
2220 FOR COMP=1 TO COMPONENTS
2230   LOCATE COMP+7,1
2240   PRINT USING "#.";COMP;
2250   PRINT USING "\                          \";TYPE$(TYPE(COMP));
```

```
RESULT SUMMARY
Outside  sound level is 70 dB(A) from angle  40 to 90 degrees
Room absorption category is intermediate

                             STC     From Table4    From Table5    Energy %
                                   (% floor area)  (spectrum)
Components:                  ------------------------------------------------
1.  Exterior wall             40     0 dB ( 83 %)      2 dB           5 %
2.  Window, openable thin     26    -4 dB ( 33 %)      1 dB          42 %
3.  Single Exterior Door      22    -6 dB ( 21 %)      0 dB          53 %

Noise reduction (adjusted 2 dB for source angle) is  23 dB
Indoor sound level is  47 dB(A) if only this surface transmits sound




-----------------------------------------------------------------------------
Options : 1. Find/change required STC for components
          2. Calculate noise reduction by specified components
          3. Load or save result file (or STOP)  ........Choose action [ 2 ]?
```

```
2260   PRINT USING "###  "; STC(COMP);
2270   IF EXPOSURE(COMP)<>SURFACE THEN GOTO 2330     'skip if on other surface
2280   AREA.PERCENT=100*AREA(COMP)/FLOOR.AREA
2290   PRINT USING "+##";CORR4(COMP); :PRINT "dB (";
2300   PRINT USING "###";AREA.PERCENT; :PRINT "%)       ";
2310   PRINT USING "+##";CORR5(COMP); :PRINT "dB       ";
2320   PRINT USING "###";ENERGY(COMP); :PRINT "%"
2330 NEXT COMP
2340 LOCATE COMP+8,1                          'now give final value below table
2350 PRINT "Noise reduction (adjusted ";
2360 PRINT USING "#";TABLE2(ANGLE(SURFACE));
2370 PRINT "dB for source angle) is "; :PRINT USING "###";ATTEN;:PRINT "dB"
2380 PRINT "Indoor sound level is ";
2390 PRINT USING "###";OUTDOOR(SURFACE)-ATTEN;
2400 PRINT " dB(A) if only this surface transmits sound"
2410 GOTO 470                                 'returns to main menu at this point
2420 '
2430 '
```

```
2440 '******************* branches here if MAIN.CHOICE=3 (SAVE OR RELOAD FILE)
2450 CLS
2460 LOCATE 5,1
2470 PRINT "Possible file operations :  1. Save current data in file"
2480 LOCATE 6,29 :PRINT "2. Load an existing file"
2490 LOCATE 7,29 :PRINT "3. None (return to main menu)"
2500 LOCATE 8,29 :PRINT "4. STOP"
2510 FILE=3                         'default file operation is to do nothing
2520 LOCATE 9,1 :PRINT "Choose case ";
2530 VALUE=FILE :GOSUB 3890 : FILE=VALUE
2540 IF FILE>4 THEN GOTO 2520    'invalid choice, so try again
2550 IF FILE=4 THEN STOP
2560 IF FILE=3 THEN GOTO 470     'return to main menu
2570 'FILE must be 1 or 2, so get filename and proceed
2580 LOCATE 11,1 :PRINT "Name of this file (";FILE$;")";  'give default filename
2590 INPUT A$ :IF LEN(A$)>0 THEN FILE$=A$    'if not accepting the default name
2600 ON FILE  GOTO 2610,2750                    'only cases 1 or 2 possible
2610 'branches here if FILE=1, to store data in a file
2620   OPEN FILE$ FOR OUTPUT AS #1
2630   'use simple sequential file structure
2640   PRINT #1,SPECTRUM,SURFACES                'outdoor noise parameters
2650   FOR SURFACE=1 TO 3
2660     PRINT #1,OUTDOOR(SURFACE),ANGLE(SURFACE)
2670   NEXT SURFACE
2680   PRINT #1,ABSORPTYPE,FLOOR.AREA,COMPONENTS,INDOOR.LEVEL      'room info
2690   FOR COMP=1 TO COMPONENTS   'now write data for each component
2700     PRINT #1,EXPOSURE(COMP),TYPE(COMP),AREA(COMP),CHOICE(COMP)
2710     PRINT #1,NR(COMP),STC(COMP),ENERGY(COMP)
2720   NEXT COMP
2730   CLOSE #1
2740   GOTO 470       'end of output action, return to main menu
2750 'flow branches here if FILE=2,  to load a datafile
2760   OPEN FILE$ FOR INPUT AS #1
2770   INPUT #1,SPECTRUM,SURFACES                'outdoor noise parameters
2780   FOR SURFACE=1 TO 3
2790     INPUT #1,OUTDOOR(SURFACE),ANGLE(SURFACE)
2800   NEXT SURFACE
2810   INPUT #1,ABSORPTYPE,FLOOR.AREA,COMPONENTS,INDOOR.LEVEL      'room info
2820   FOR COMP=1 TO COMPONENTS
2830     INPUT #1,EXPOSURE(COMP),TYPE(COMP),AREA(COMP),CHOICE(COMP)
2840     INPUT #1,NR(COMP),STC(COMP),ENERGY(COMP)
2850   NEXT COMP
2860   CLOSE #1
2870 GOTO 470            'return to main menu after file input complete
2880 '
2890 '
```

```
2900 ' ************************************************** SUBROUTINES, ETC.
2910 '
2920 ' GOSUB to get number of outdoor source cases SURFACES
2930 LOCATE 3,1 :PRINT "Noise outside is : "
2940 LOCATE 3,20 :PRINT "1. same for all exterior surfaces"
2950 LOCATE 4,20 :PRINT "2. two different noise exposures"
2960 LOCATE 5,20 :PRINT "3. three different noise exposures"
2970 LOCATE 5,55 :PRINT " ....Choose case ";
2980 VALUE=SURFACES :GOSUB 3890 :SURFACES=VALUE
2990 RETURN
3000 '
3010 ' GOSUB to get index for Table2, ANGLE(SURFACE)
3020 ANGLE$(1)="  60 to 90 degrees"        'these are used as prompts later
3030 ANGLE$(2)="  40 to 90 degrees"
3040 ANGLE$(3)="  30 to 90 degrees"
3050 ANGLE$(4)="   0 to 90 degrees"
3060 LOCATE 11,1 :PRINT "Sound arrives from angular range:  "
3070 FOR I=1 TO 4
3080   LOCATE I+11,15 :PRINT I;".";ANGLE$(I)
3090 NEXT I
3100 Y=15-SURFACES                             'vertical prompt location
3110 IF SURFACE=1 THEN LOCATE Y+SURFACE,40 :PRINT ".... Nearest case "
3120 LOCATE Y+SURFACE,58 :PRINT SURFACE$;
3130 VALUE=ANGLE(SURFACE) :GOSUB 3890 : ANGLE(SURFACE)=VALUE
3140 RETURN
3150 '
3160 ' GOSUB to get index SPECTRUM for source frequency content
3170 LOCATE 17,1 :PRINT "Noise spectrum category :"
3180 LOCATE 18,10 :PRINT "1. jet aircraft landing"
3190 LOCATE 19,10 :PRINT "2. average aircraft noise, or railway wheel noise"
3200 LOCATE 20,10 :PRINT "3. railway wheel noise screened by a barrier"
3210 LOCATE 21,10 :PRINT "4. mixed road traffic, or distant aircraft"
3220 LOCATE 22,10 :PRINT "5. road traffic screened by a barrier"
3230 LOCATE 23,10 :PRINT "6. diesel railway locomotives"
3240 LOCATE 23,50 :PRINT ".........Nearest case ";
3250 VALUE=SPECTRUM :GOSUB 3890 :SPECTRUM=VALUE
3260 RETURN
3270 '
3280 ' GOSUB to get  floor area, index for absorption, no. of components
3290 LOCATE 8,1 :PRINT "In your choice of units, give room floor area : ";
3300 VALUE=FLOOR.AREA :GOSUB 3890 : FLOOR.AREA=VALUE
3310 LOCATE 10,1 :PRINT "Category for room furnishings :"
3320 LOCATE 11,5 :PRINT "1. hard (e.g.- kitchens, or bathrooms)"
3330 LOCATE 12,5 :PRINT "2. intermediate (carpet or soft furniture)"
3340 LOCATE 13,5 :PRINT "3. very absorptive (e.g.- carpeted bedroom)"
3350 LOCATE 13,50 :PRINT "...... Nearest case "; :VALUE=ABSORPTYPE
3360 GOSUB 3890 :ABSORPTYPE=VALUE
3370 IF ABSORPTYPE=1 THEN ROOM$="low absorption"
3380 IF ABSORPTYPE=2 THEN ROOM$="intermediate"
3390 IF ABSORPTYPE=3 THEN ROOM$="high absorption"
3400 LOCATE 15,1
3410 PRINT "Exterior surface components include walls, windows, etc."
3420 LOCATE 16,1 :PRINT "Number of components  ";
3430 VALUE=COMPONENTS :GOSUB 3890 : COMPONENTS=VALUE
3440 RETURN
3450 '
```

```
3460 ' GOSUB to set SURFAC to appropriate one of multiple surfaces
3470 ON SURFACES GOTO 3480,3500,3500  !There may be 1,2, or 3 surfaces
3480 SURFAC=1        'if only one exterior exposure case, this is it
3490   RETURN        'no further questions needed, so return
3500 PRINT " - identify the relevant surface:"      'if more than one
3510   FOR SURF=1 TO SURFACES
3520     PRINT USING "#";SURF; :PRINT ") Sound level ";
3530     PRINT USING "##";OUTDOOR(SURF); :PRINT " dB(A) from angle ";
3540     PRINT USING "\                \"; ANGLE$(ANGLE(SURF));
3550     IF SURF<SURFACES THEN PRINT
3560   NEXT SURF
3570   PRINT "... Choose case ";
3580   VALUE=SURFAC :GOSUB 3890 : SURFAC=VALUE
3590 RETURN
3600 '
3610 ' GOSUB to get component category, and correction from Table5
3620 TYPE$(1)=" Single Exterior Door"
3630 TYPE$(2)=" Double Exterior Door"
3640 TYPE$(3)=" Window, single glazed"
3650 TYPE$(4)=" Window, openable thin  double or triple"
3660 TYPE$(5)=" Window, sealed  thin   double or triple"
3670 TYPE$(6)=" Window, openable thick double or triple"
3680 TYPE$(7)=" Window, sealed  thick   double glazed"
3690 TYPE$(8)=" Exterior wall "
3700 TYPE$(9)=" Roof / ceiling"
3710 LOCATE 3,1 :PRINT "Component type:";
3720 FOR I=1 TO 9
3730   LOCATE 2+I,16 :PRINT I;". ";TYPE$(I)
3740 NEXT I
3750 LOCATE 11,45 :PRINT ".......... Nearest case ";
3760 VALUE=TYPE(COMP) :GOSUB 3890 :TYPE(COMP)=VALUE
3770 ON TYPE(COMP) GOTO 3790,3810,3810,3810,3830,3830,3850,3850,3850
3780 GOTO 3750       'repeat the input if TYPE(COMP) not a valid case  above
3790 CORR5(COMP)=TABLE5(1,SPECTRUM) 'select value from table
3800   RETURN
3810 CORR5(COMP)=TABLE5(2,SPECTRUM)
3820   RETURN
3830 CORR5(COMP)=TABLE5(3,SPECTRUM)
3840   RETURN
3850 CORR5(COMP)=TABLE5(4,SPECTRUM)
3860 RETURN
3870 '
3880 ' GOSUB to show default value and assign new value to VALUE
3890 PRINT "[";VALUE;"]";
3900 INPUT ; A$
3910 IF LEN(A$)>0 THEN VALUE=VAL(A$)
3920 RETURN
3930 END
```