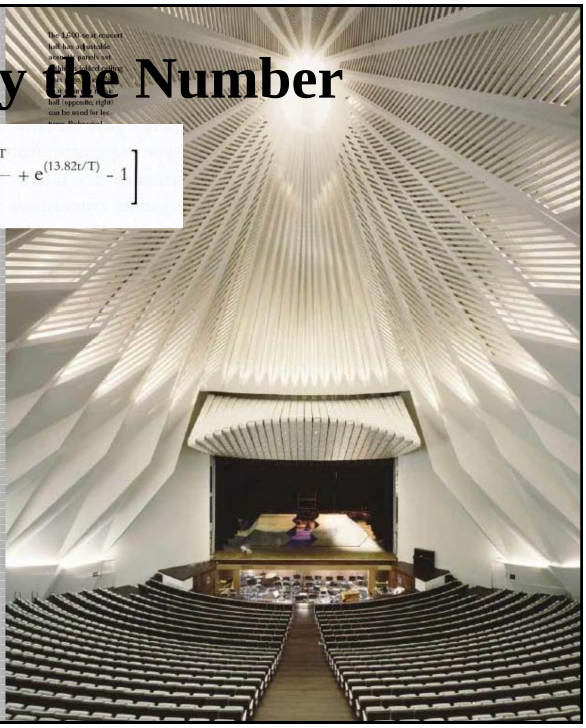
Acoustics by the Number

$$C_t = 10 \log_{10}\left[\frac{Ve^{(0.04r+13.82t)/T}}{312Tr^2} + e^{(13.82t/T)} - 1\right]$$

clarity



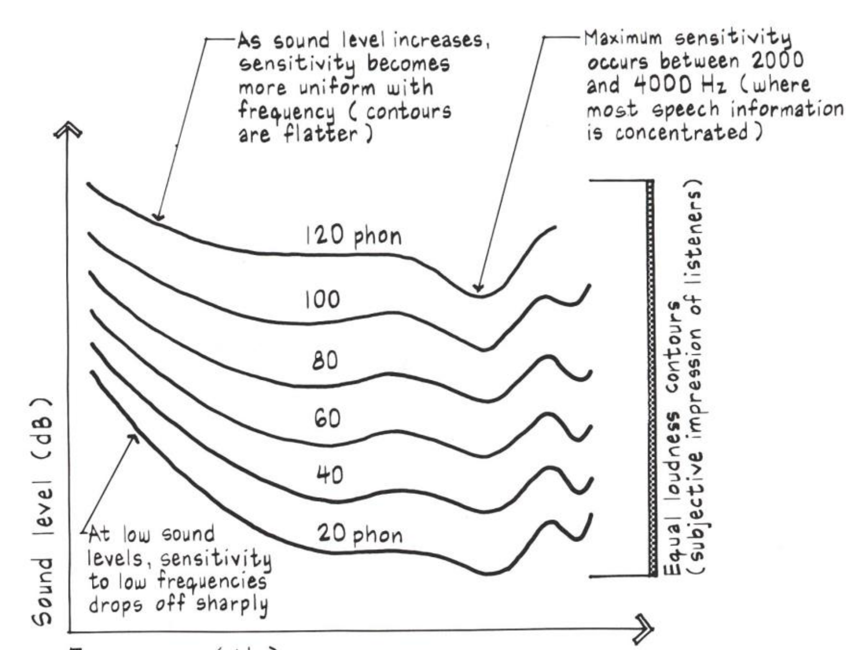
Auditorio de Tenefire
Calatrava

1

Cast of Characters

dBA	Decibel scale adjusted for human ear sensitivity (dB)
α	Coefficient of absorption (ratio)
A	Total absorption (sabines)
T_R	Reverberation time (seconds)
STC	Sound Transmission Class (dB)
NR	Noise reduction (dB)

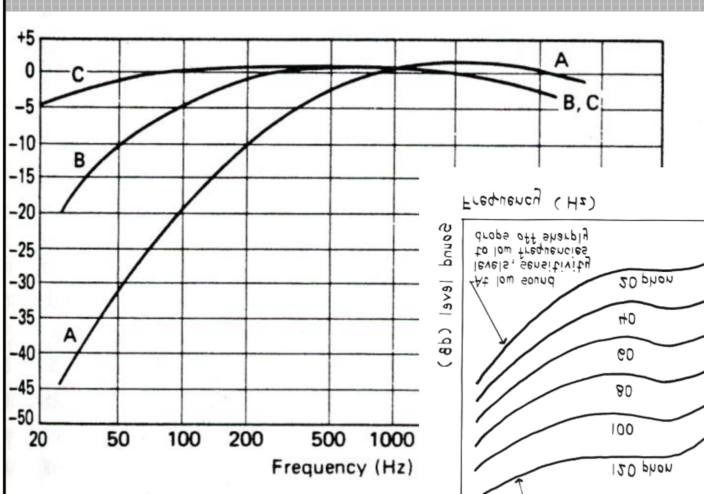
2

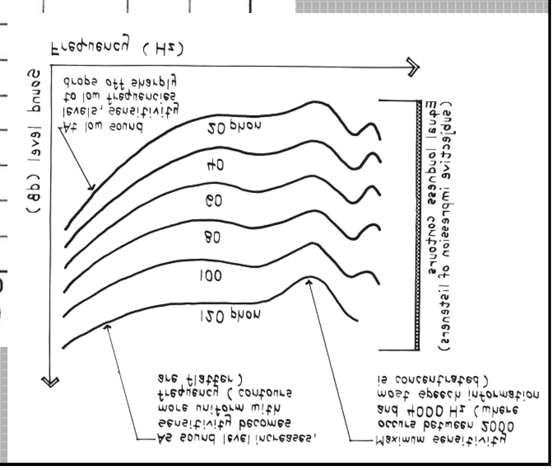


Human Ear Sensitivity

3

Not all decibels are heard equally, so…





…we use dBA to model ear sensitivity…

4

Coefficient of absorption $\alpha = I_a/I_i$ (absorbed over incident)

SOUND ABSORPTION DATA FOR COMMON BUILDING MATERIALS AND FURNISHINGS

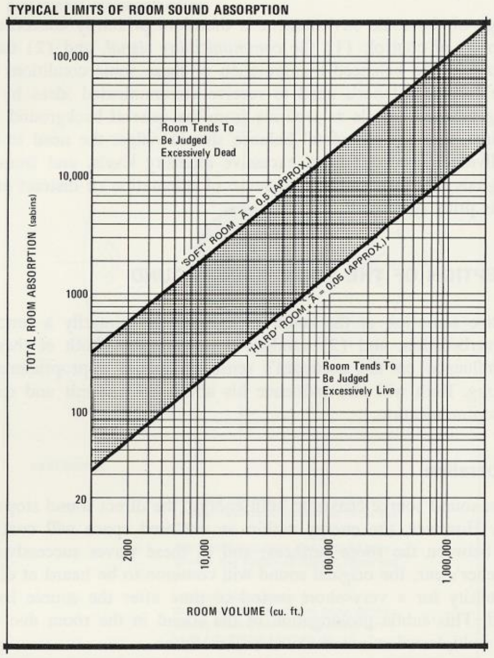
Material	Sound Absorption Coefficient 125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	NRC Number*
Walls (1-3, 9, 12)							
Sound-Reflecting:							
1. Brick, unglazed	0.02	0.02	0.03	0.04	0.05	0.07	0.05
2. Brick, unglazed and painted	0.01	0.01	0.02	0.02	0.02	0.03	0.00
3. Concrete, rough	0.01	0.02	0.04	0.06	0.08	0.10	0.05
4. Concrete block, painted	0.10	0.05	0.06	0.07	0.09	0.08	0.05
5. Glass, heavy (large panes)	0.18	0.06	0.04	0.03	0.02	0.02	0.05
6. Glass, ordinary window	0.35	0.25	0.18	0.12	0.07	0.04	0.15
7. Gypsum board, 1/2 in thick (nailed to 2 × 4s, 16 in oc)	0.29	0.10	0.05	0.04	0.07	0.09	0.05
• 8. Gypsum board, 1 layer, 5/8 in thick (screwed to 1 × 3s, 16 in oc with airspaces filled with fibrous insulation)	0.55	0.14	0.08	0.04	0.12	0.11	0.10
9. Construction no. 8 with 2 layers of 5/8-in-thick gypsum board	0.28	0.12	0.10	0.07	0.13	0.09	0.10
10. Marble or glazed tile	0.01	0.01	0.01	0.01	0.02	0.02	0.00
11. Plaster on brick	0.01	0.02	0.02	0.03	0.04	0.05	0.05
12. Plaster on concrete block (or 1 in thick on lath)	0.12	0.09	0.07	0.05	0.05	0.04	0.05
13. Plaster on lath	0.14	0.10	0.06	0.05	0.04	0.03	0.05
14. Plywood, 3/8-in paneling	0.28	0.22	0.17	0.09	0.10	0.11	0.15
15. Steel	0.05	0.10	0.10	0.10	0.07	0.02	0.10
16. Venetian blinds, metal	0.06	0.05	0.07	0.15	0.13	0.17	0.10
17. Wood, 1/4-in paneling, with airspace behind	0.42	0.21	0.10	0.08	0.06	0.06	0.10
18. Wood, 1-in paneling with airspace behind	0.19	0.14	0.09	0.06	0.06	0.05	0.10

Etc.

5

FIGURE 1–2.4

TYPICAL LIMITS OF ROOM SOUND ABSORPTION



Total Absorption

$$A = \Sigma S\alpha$$

Where

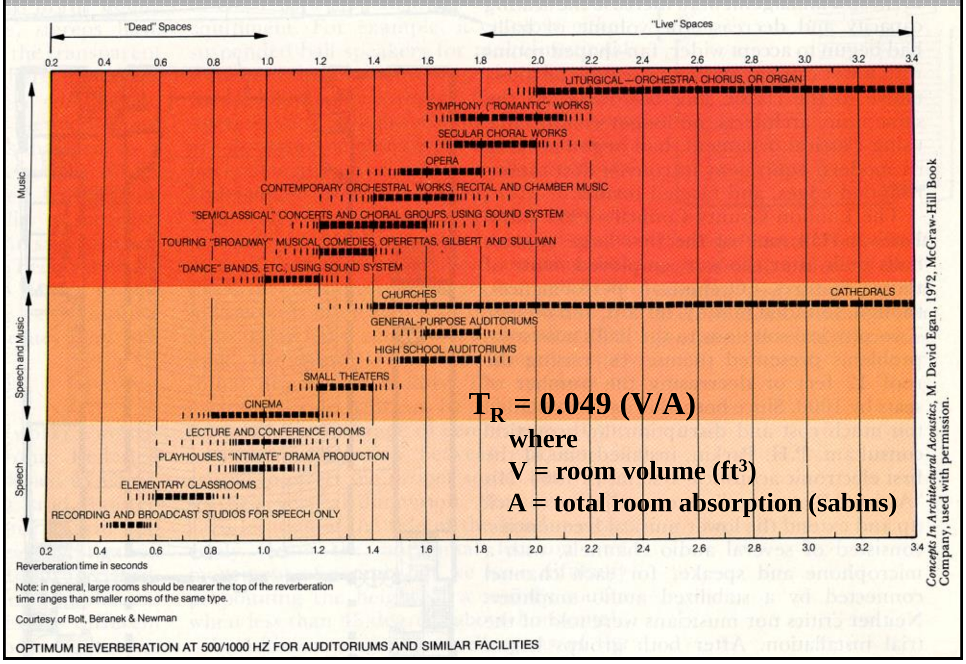
α is coefficient of absorption

S is area in ft^2

A is absorption in Sabins

6

Reverberation Time



$$T_R = 0.049\,(V/A)$$

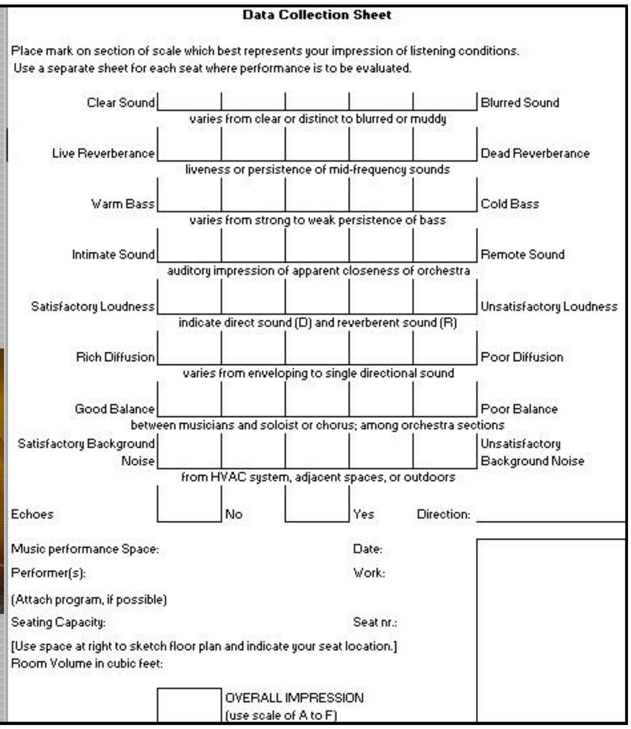
where

V = room volume (ft^3)

A = total room absorption (sabins)

7

Extra Credit #4 gives you a chance to perform a subjective evaluation of a performance space…



Data Collection Sheet

Place mark on section of scale which best represents your impression of listening conditions.
Use a separate sheet for each seat where performance is to be evaluated.

Clear Sound | | | | | | Blurred Sound
varies from clear or distinct to blurred or muddy

Live Reverberance | | | | | | Dead Reverberance
liveness or persistence of mid-frequency sounds

Warm Bass | | | | | | Cold Bass
varies from strong to weak persistence of bass

Intimate Sound | | | | | | Remote Sound
auditory impression of apparent closeness of orchestra

Satisfactory Loudness | | | | | | Unsatisfactory Loudness
indicate direct sound (D) and reverberent sound (R)

Rich Diffusion | | | | | | Poor Diffusion
varies from enveloping to single directional sound

Good Balance | | | | | | Poor Balance
between musicians and soloist or chorus; among orchestra sections

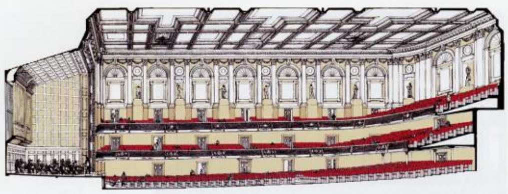
Satisfactory Background Noise | | | | | | Unsatisfactory Background Noise
from HVAC system, adjacent spaces, or outdoors

Echoes | | No | | Yes Direction: ______

Music performance Space: Date:
Performer(s): Work:
(Attach program, if possible)
Seating Capacity: Seat nr.:
[Use space at right to sketch floor plan and indicate your seat location.]
Room Volume in cubic feet:

OVERALL IMPRESSION
(use scale of A to F)

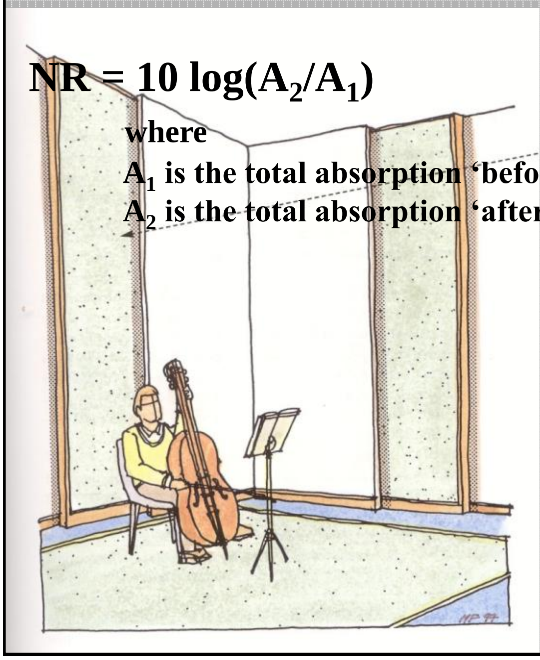
8



Subjective term	Description of precept	Proposed objective measure
Loudness	Strength or loudness of a sound	Total sound (pressure) level (Source strength)—G (A-weighted)
Clarity	Articulation—the ability to hear definition and detail, often relating to speech or faster tempo music	Early-to-late sound ratio—C_{40}, C_{80} (level adjusted)
Intimacy	Apparent closeness of sound	ITG or "Initial time gap"
Reverberance	Perception of reflected sound and liveness	Early sound reflections, EDT (125 Hz to 4 kHz SEG ratio, ISE-T_5)
Envelopment	Immersion in a sound field, the sense of being surrounded	Late lateral sound level (after 80 msec)
Brightness	Relative loudness of treble or high frequency sounds compared to mid-frequency sound	2 to 4 kHz sound level and reverberation time
Bass warmth	The relative loudness of bass or low frequency sounds compared to the mid-frequency sounds	Early low frequency sound level—125 to 500 Hz values of G in the first 50 msec

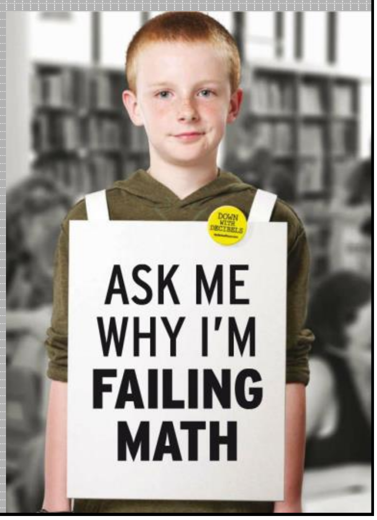
9

Noise Reduction (within a room)

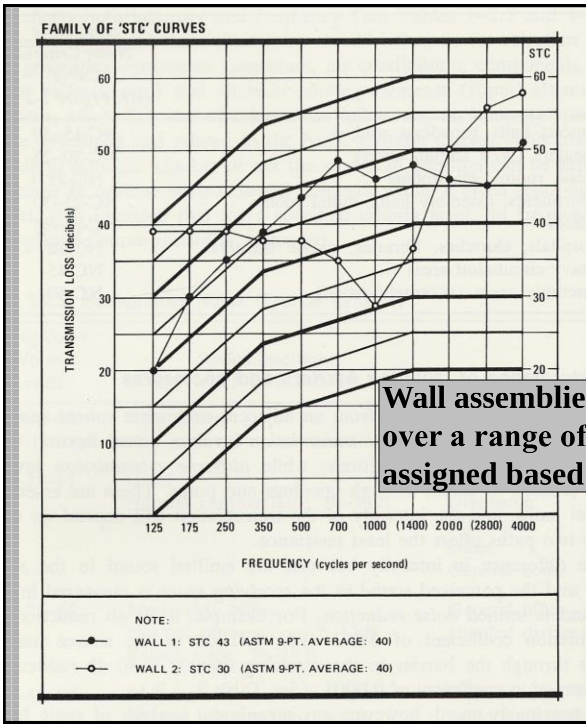


$$NR = 10 \log(A_2/A_1)$$

where
A_1 is the total absorption 'before'
A_2 is the total absorption 'after'



10

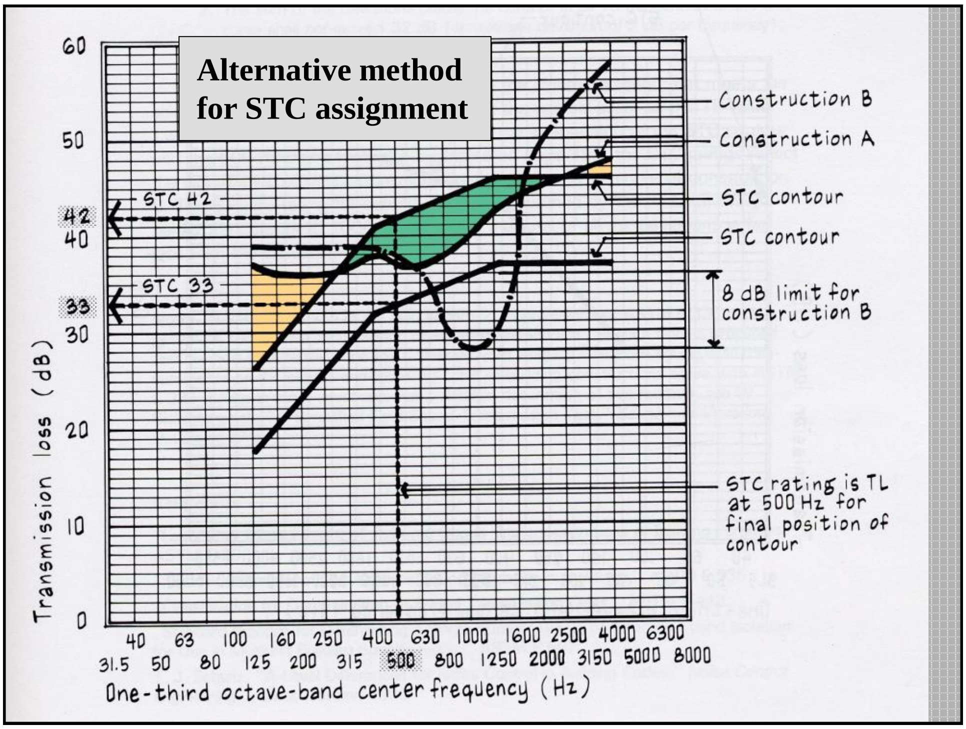


STC

See MEEB app K

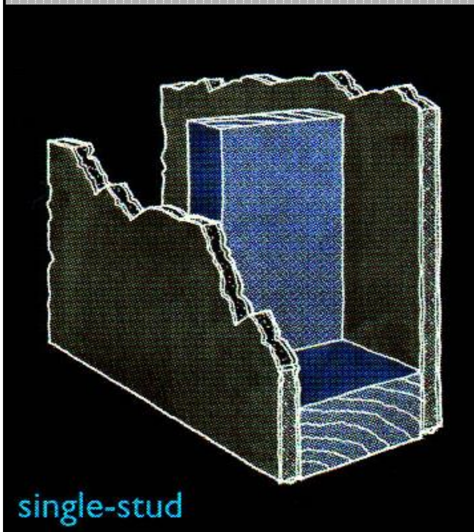
Wall assemblies are tested for attenuation over a range of frequencies…and STC is assigned based on average TL (dB)

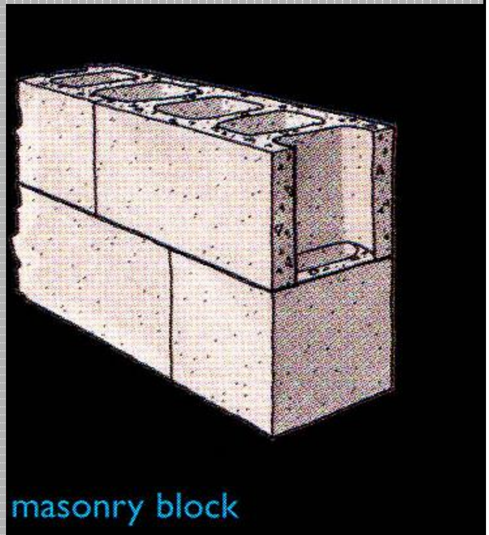
Alternative method for STC assignment



STC

- **Barriers... Mass is best**



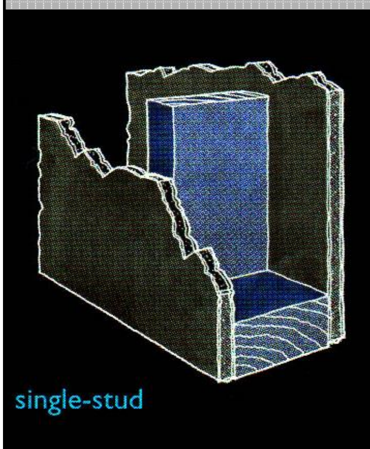


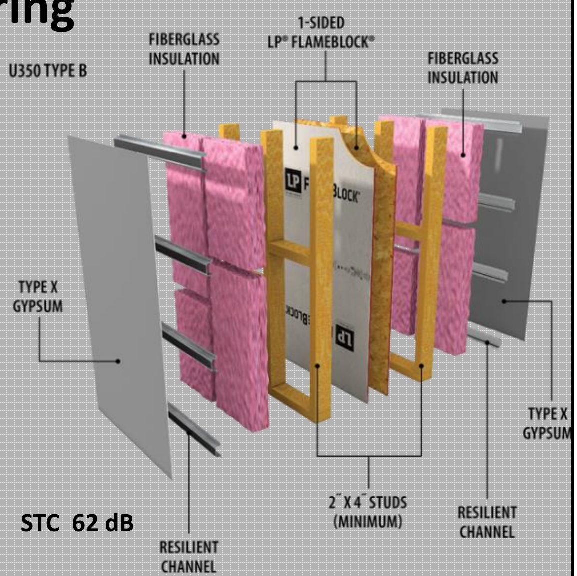
STC 34 dB **STC 46 dB**

13

STC

- **Barriers...Layering**



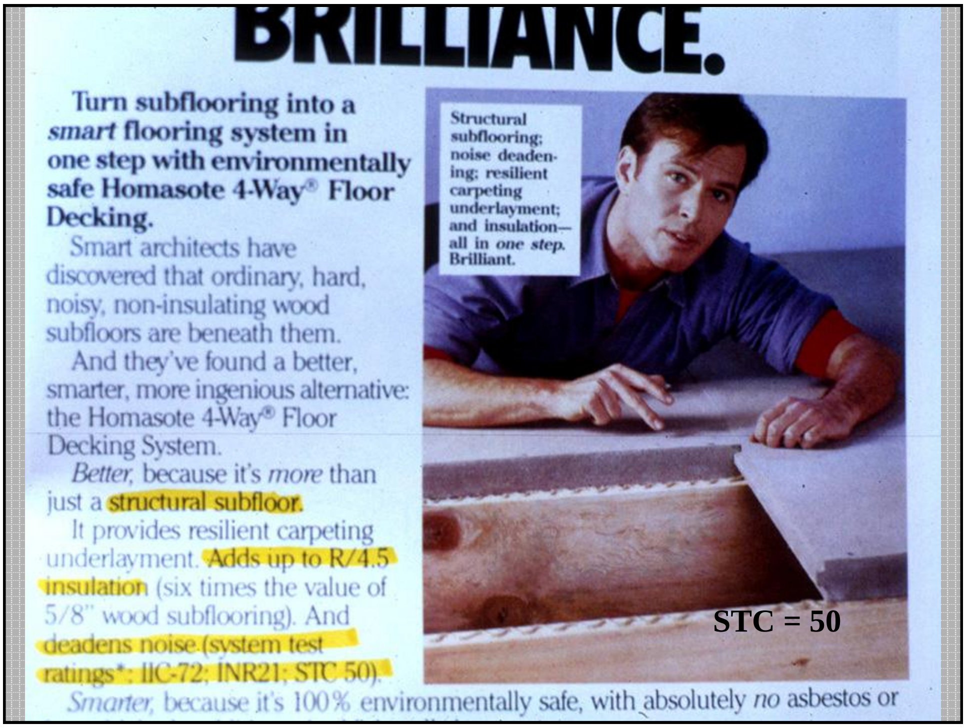


STC 34 dB
Typical wall

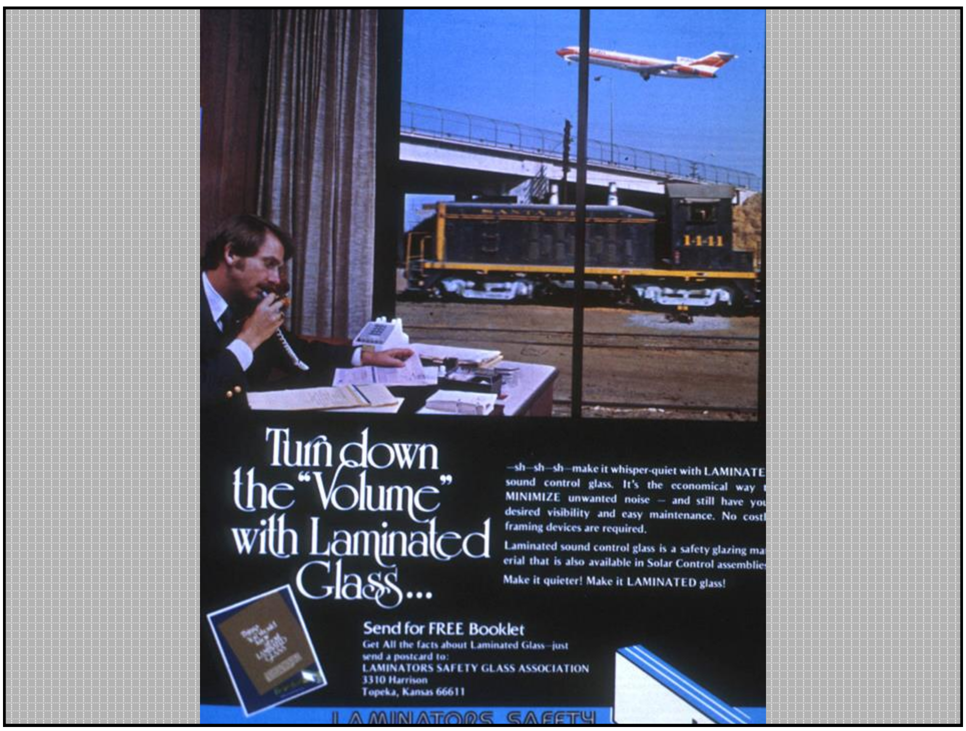
STC 62 dB

+ provides fire protection

14


BRILLIANCE.
Turn subflooring into a *smart* flooring system in one step with environmentally safe Homasote 4-Way® Floor Decking.
Smart architects have discovered that ordinary, hard, noisy, non-insulating wood subfloors are beneath them.
And they've found a better, smarter, more ingenious alternative: the Homasote 4-Way® Floor Decking System.
Better, because it's *more* than just a structural subfloor.
It provides resilient carpeting underlayment. Adds up to R/4.5 insulation (six times the value of 5/8" wood subflooring). And deadens noise (system test ratings*: IIC-72; INR21; STC 50).
Smarter, because it's 100% environmentally safe, with absolutely *no* asbestos or
Structural subflooring; noise deadening; resilient carpeting underlayment; and insulation—all in *one step.* Brilliant.
STC = 50

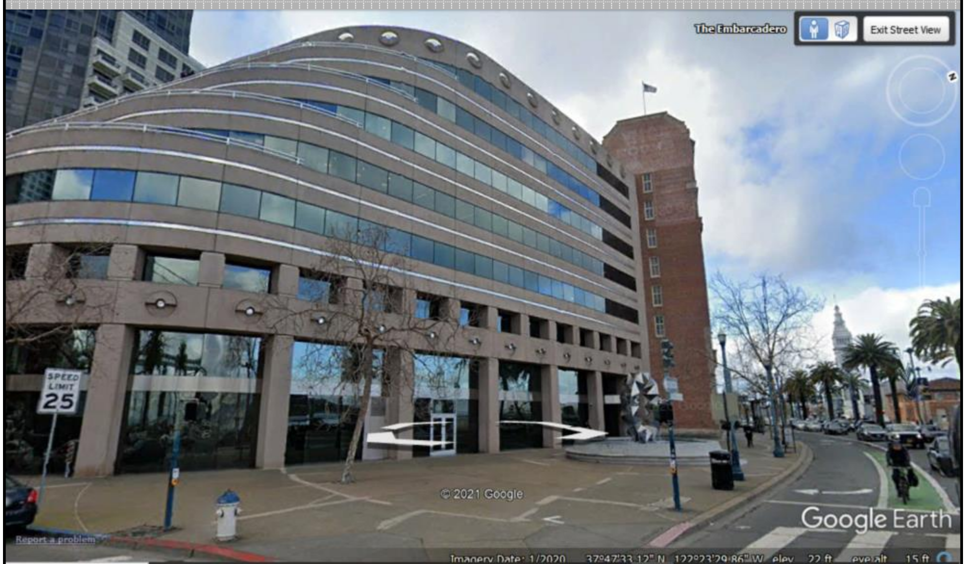
15


Turn down the "Volume" with Laminated Glass...
—sh—sh—sh—make it whisper-quiet with LAMINATE
sound control glass. It's the economical way
MINIMIZE unwanted noise — and still have you
desired visibility and easy maintenance. No cost
framing devices are required.
Laminated sound control glass is a safety glazing ma
erial that is also available in Solar Control assemblie
Make it quieter! Make it LAMINATED glass!
Send for FREE Booklet
Get All the facts about Laminated Glass—just send a postcard to:
LAMINATORS SAFETY GLASS ASSOCIATION
3310 Harrison
Topeka, Kansas 66611
LAMINATORS SAFETY

16

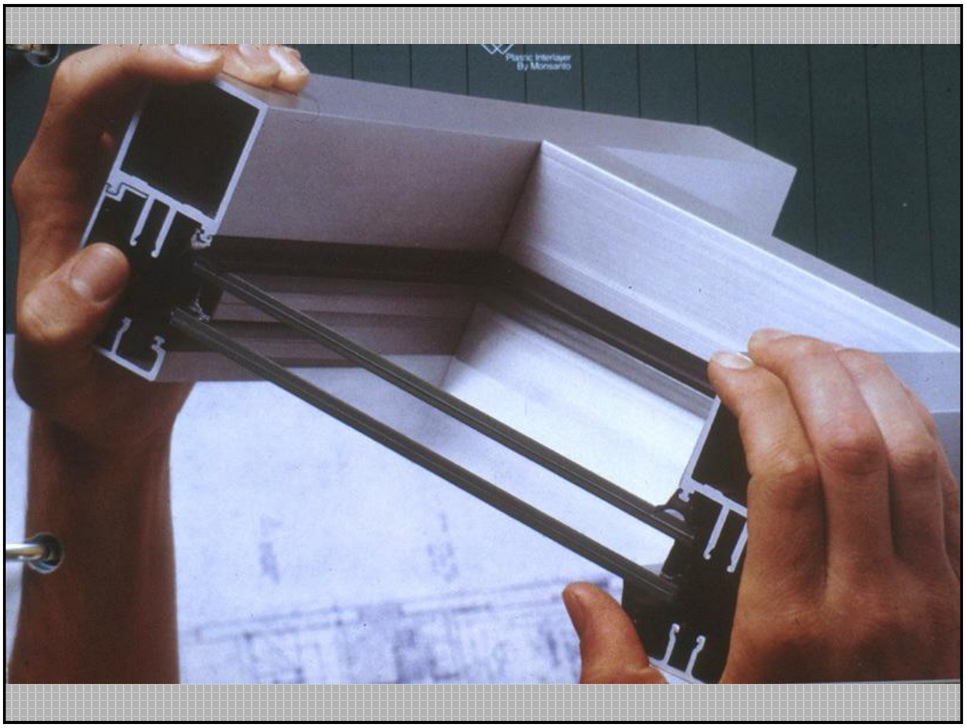
17

After Loma Prieta Earthquake



The building remains, the freeway doesn't!

18



19

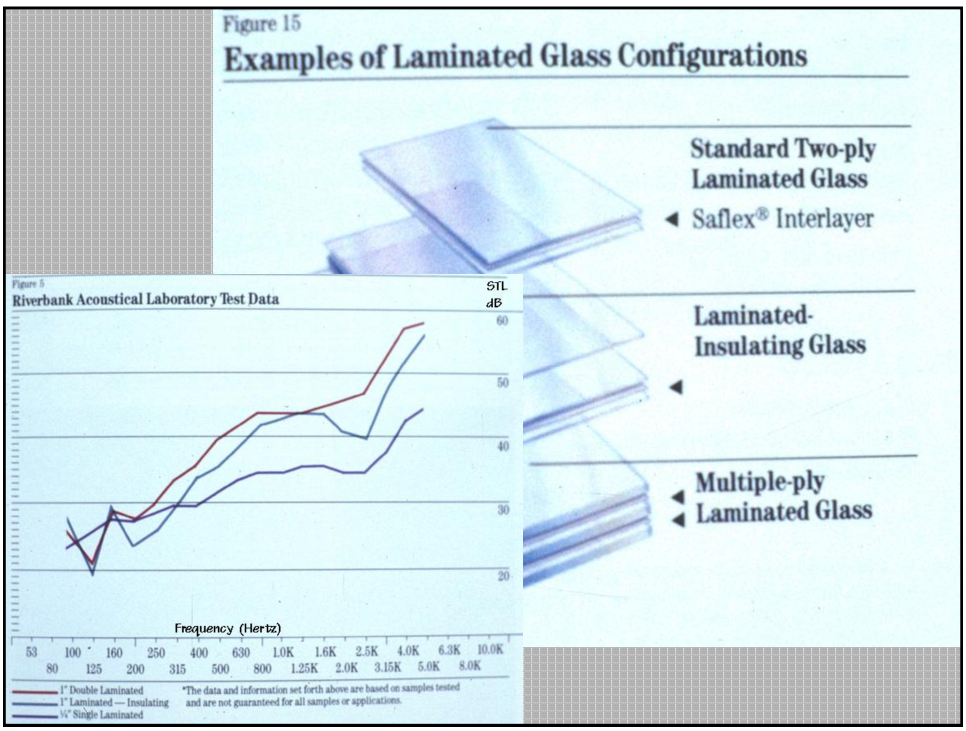
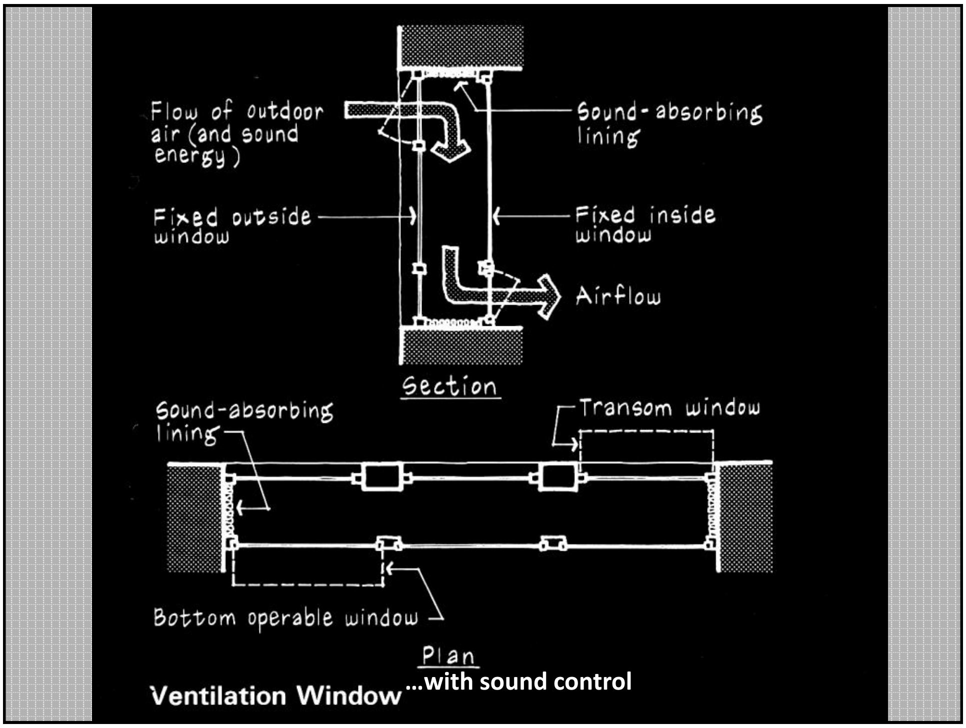
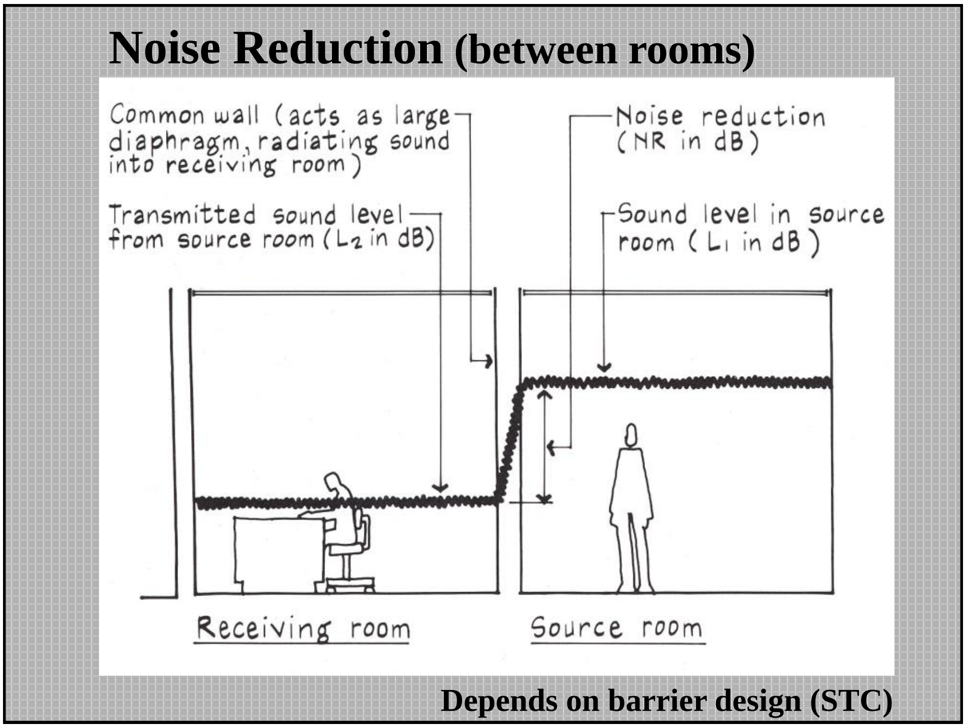


Figure 15
Examples of Laminated Glass Configurations
Standard Two-ply Laminated Glass
Saflex® Interlayer
Laminated-Insulating Glass
Multiple-ply Laminated Glass
Figure 5
Riverbank Acoustical Laboratory Test Data
STL dB
60
50
40
30
20
Frequency (Hertz)
53 100 160 250 400 630 1.0K 1.6K 2.5K 4.0K 6.3K 10.0K
80 125 200 315 500 800 1.25K 2.0K 3.15K 5.0K 8.0K
1" Double Laminated
1" Laminated — Insulating
¼" Single Laminated
*The data and information set forth above are based on samples tested and are not guaranteed for all samples or applications.

20


Flow of outdoor air (and sound energy)
Sound-absorbing lining
Fixed outside window
Fixed inside window
Airflow
Section
Sound-absorbing lining
Transom window
Bottom operable window
Plan
Ventilation Window
...with sound control

21


Noise Reduction (between rooms)
Common wall (acts as large diaphragm, radiating sound into receiving room)
Transmitted sound level from source room (L2 in dB)
Noise reduction (NR in dB)
Sound level in source room (L1 in dB)
Receiving room
Source room
Depends on barrier design (STC)

22

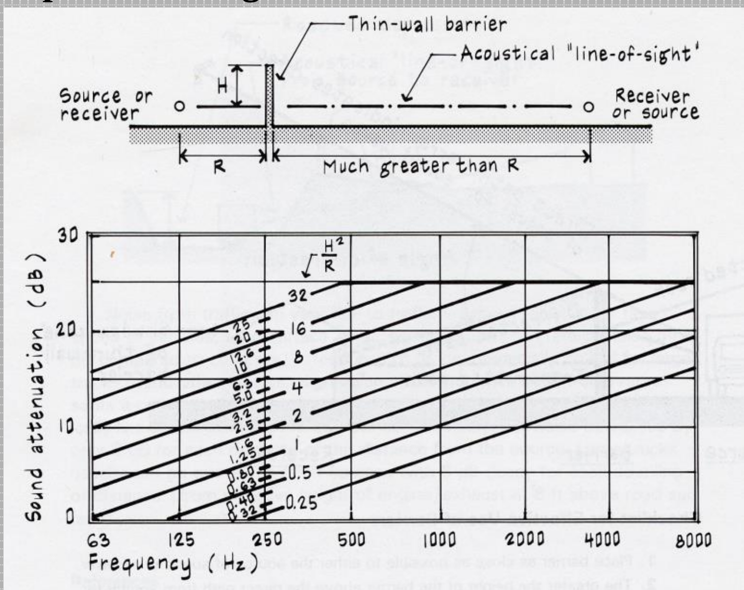
Noise Criteria

Type of Space (and Listening Requirements)	Preferred Range of Noise Criteria	Equivalent dBA Level*
Concert halls, opera houses, broadcasting and recording studios, large auditoriums, large churches, recital halls (for excellent listening conditions)	< NC-20	< 30
Small auditoriums, theaters, music practice rooms, large meeting rooms, teleconference rooms, audiovisual facilities, large conference rooms, executive offices, small churches, courtrooms, chapels (for very good listening conditions)	NC-20 to NC-30	30 to 38
Bedrooms, sleeping quarters, hospitals, residences, apartments, hotels, motels (for sleeping, resting, relaxing)	NC-25 to NC-35	34 to 42
Private or semiprivate offices, small conference rooms, classrooms, libraries (for good listening conditions)	NC-30 to NC-35	38 to 42
Large offices, reception areas, retail shops and stores, cafeterias, restaurants, gymnasiums (for moderately good listening conditions)	NC-35 to NC-40	42 to 47
Lobbies, laboratory work spaces, drafting and engineering rooms, general secretarial areas, maintenance shops such as for electrical equipment (for fair listening conditions)	NC-40 to NC-45	47 to 52
Kitchens, laundries, school and industrial shops, computer equipment rooms (for moderately fair listening conditions)	NC-45 to NC-55	52 to 61

*Do *not* use A-weighted sound levels (dBA) for specification purposes. Spectrum shapes and noise characteristics can vary widely for background noises with identical A-weighted sound levels (see Chap. 1).

23

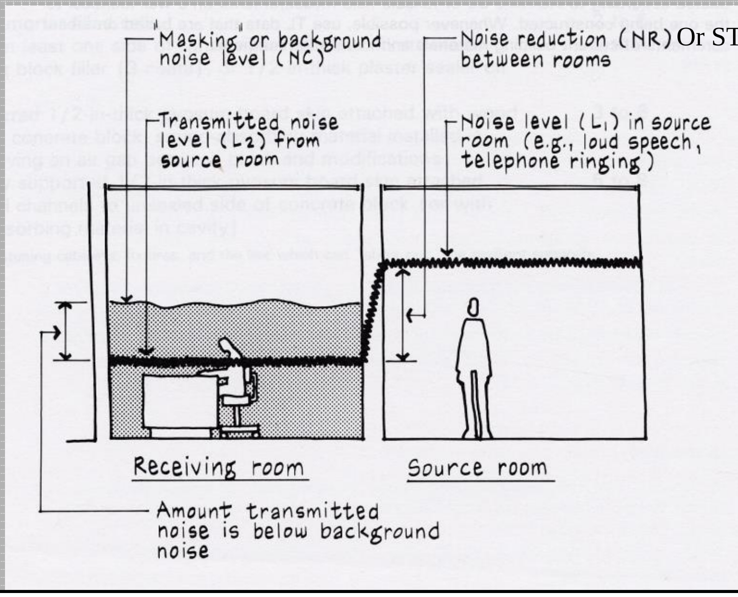
Outdoors in a free field sound attenuation depends on height and distance



Barrier Attenuation Graph

24

Indoors it depends on the design of the barrier and the level of background noise…

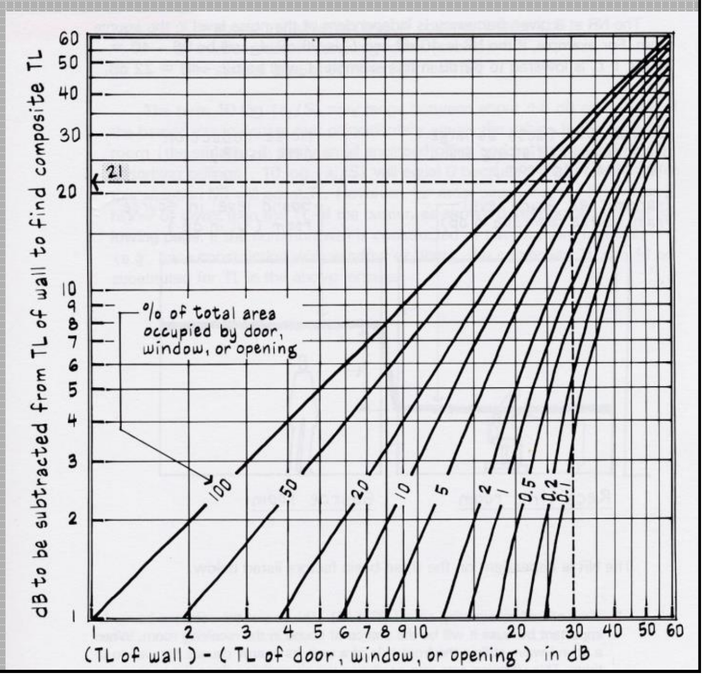


25

Transmission Loss of composite walls can be calculated …

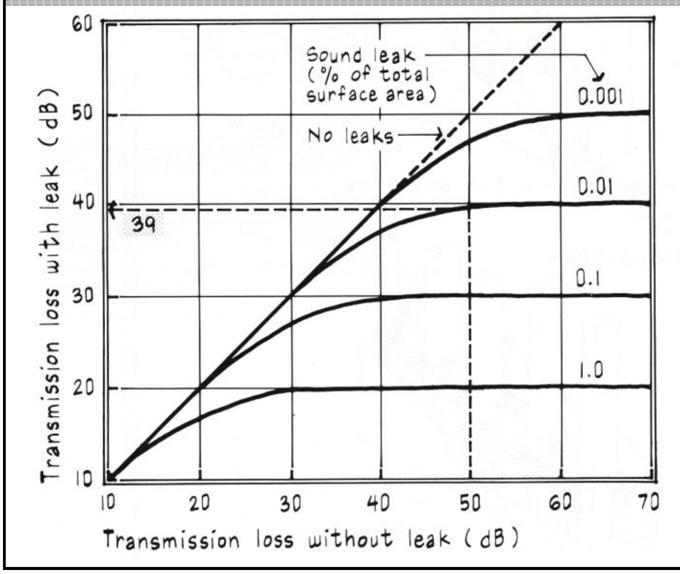
Use STCs to find ΔTL

Weight result by % of opening



26

Transmission Loss of walls with holes can be calculated …



Based on wall STC and % of wall open

Each hole size (%) has a peak performance

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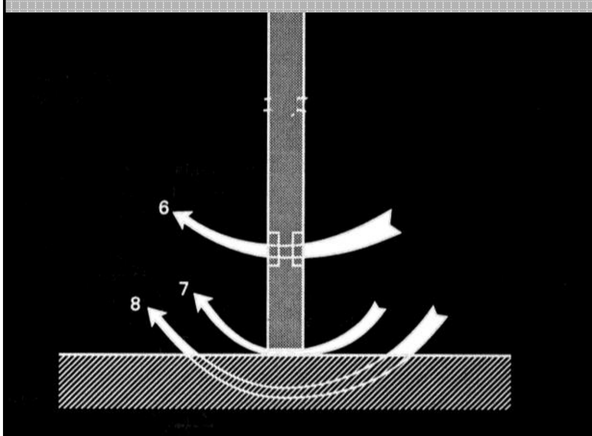
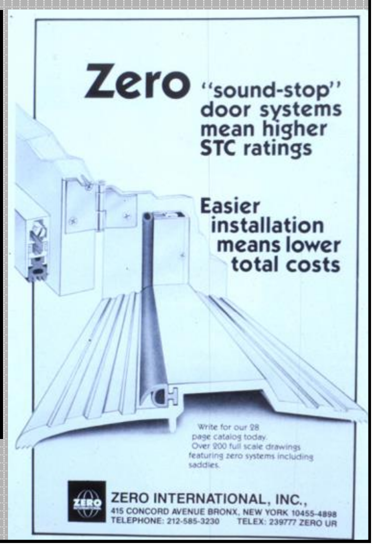
STC maintenance

- **Barriers... Block Acoustic Bridges**



- **Don’t line-up electrical outlets**
- **Seal bottom (& top) of wall**

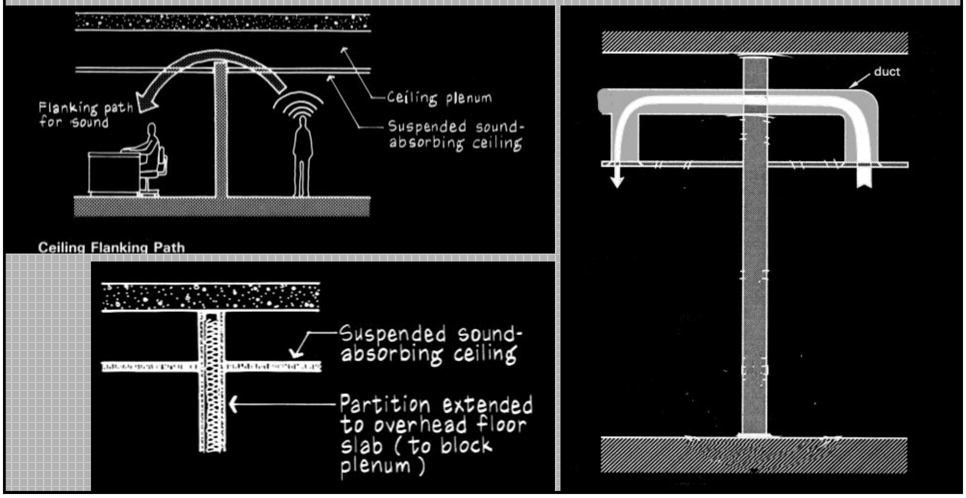


28

STC maintenance

- Barriers... Block acoustic bridges

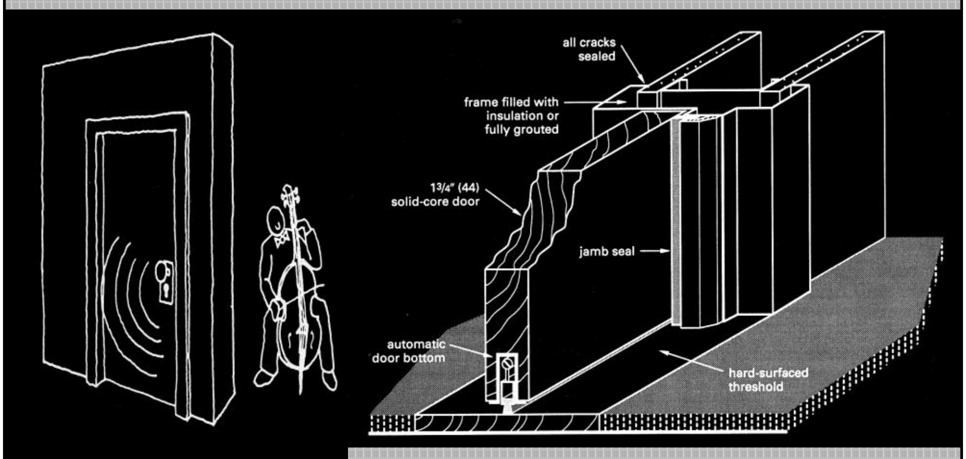
Plenums and HVAC Ducts



29

STC maintenance

- Barriers... Block Acoustic Bridges



Caulk and weatherstrip doors

30

Sound levels in rooms can be calculated …

Example Source	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	dBA
	Sound Pressure Level (dB)								
Home									
Alarm clock at 4 to 9 ft (ringing)	..	46	48	55	62	62	70	80	80
Electric shaver at 1 ½ ft	59	58	49	62	60	64	60	59	68
Vacuum cleaner at 3 ft	48	66	69	73	79	73	73	72	81
Garbage disposal at 2 ft	64	83	69	56	55	50	50	49	69
Clothes washer at 2 to 3 ft (wash cycle)	59	65	59	59	58	54	50	46	62
Toilet (refilling tank)	50	55	53	54	57	56	57	52	63
Whirlpool, six nozzles (filling tub)	68	65	68	69	71	71	68	65	74
Window air-conditioning unit	64	64	65	56	53	48	44	37	59
Telephone at 4 to 13 ft (ringing)	..	41	44	56	68	73	69	83	83
TV at 10 ft	49	62	64	67	70	68	63	39	74
Stereo (teenager listening level)	60	72	83	82	82	80	75	60	86
Stereo (adult listening level)	56	66	75	72	70	66	64	48	75
Violin at 5 ft (fortissimo)	..	..	91	91	87	83	79	66	92
Normal conversational speech at 3 ft	..	57	62	63	57	48	40	..	63
Outdoors									
Birds at 10 ft	..	..	..	..	..	50	52	54	57
Cicadas	..	..	..	..	35	51	54	48	57
Large dog at 50 ft (barking)	..	50	58	68	70	64	52	48	72
Lawn mower at 5 ft	85	87	86	84	81	74	70	72	86
Pistol shot at 250 ft (peak impulse levels)	..	..	..	83	91	99	102	106	106
Surf at 10 to 15 ft (moderate seas)	71	72	70	71	67	64	58	54	78
Wind in trees (10 mi/h)	..	..	..	33	35	37	37	35	43

Etc.

31

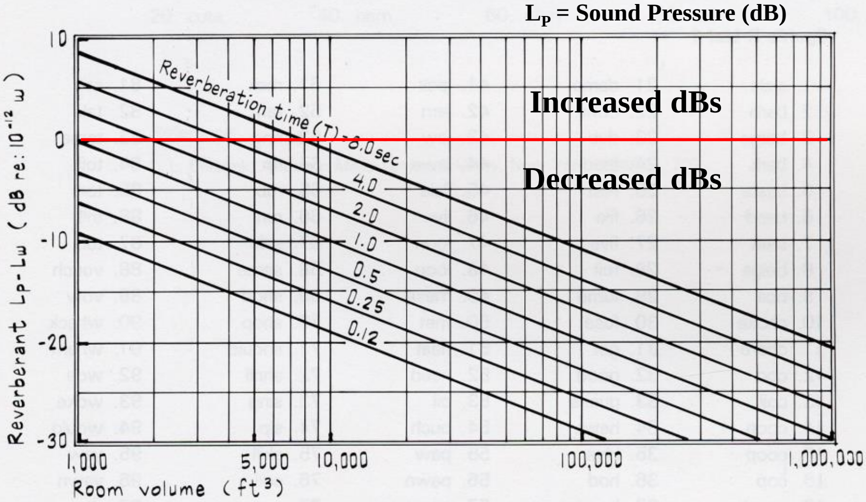
Based on T_R and room volume…

REVERBERANT $L_P - L_W$ GRAPH

A 1000-ft³ room has a reverberation time T of 1.4 s at 500 Hz. To find the L_P of a 30-hp electric motor with a L_W of 93 dB at 500 Hz, enter graph at 1000 ft³ and read opposite $T = 1.4$ s curve to 1 dB. Therefore, $L_P - L_W = 1$ dB and $L_P = 93 + 1 = 94$ dB at 500 Hz.

L_W = Sound Power (dB)

L_P = Sound Pressure (dB)



32

…and then adding all the sources…logarithmically…

Hint: Start with the loudest and add on the next loudest and so on…

Difference in dB Level	Add to Larger dB Level
0	3.0
1	2.5
2	2.1
3	1.8
4	1.5
5	1.2
6	1.0
7	0.8
8	0.6
9	0.5
10	0.4

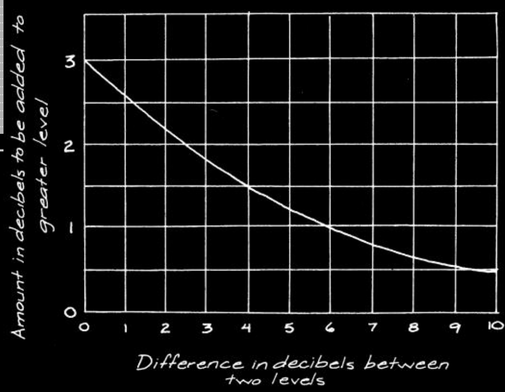
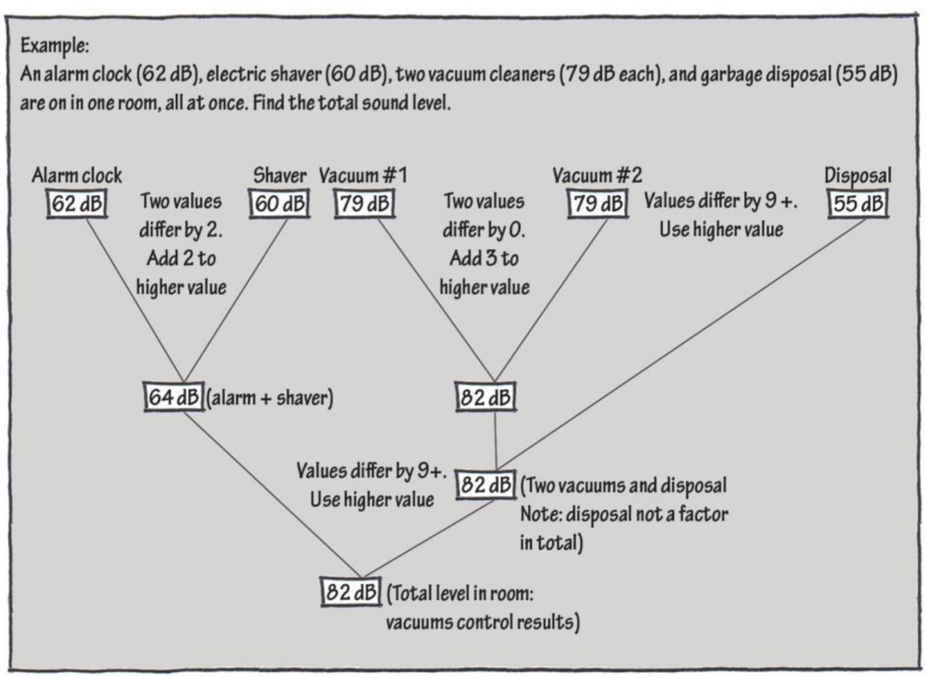


Figure B3.1.2 Nomograph for Adding Decibel Levels

33



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