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A Survey of Sound Levels in Five Unoccupied Houses

Report of the Flair Homes
Enerdemo Canada/CHBA Mark XIV Project

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A SURVEY OF SOUND LEVELS IN FIVE UNOCCUPIED HOUSES

PART OF THE

FLAIR HOMES ENERGY DEMO/CHBA FLAIR MARK XIV PROJECT

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JUNE, 1988

SUMMARY

Sound level measurements were performed in five unoccupied, unfurnished houses located in Winnipeg as part of the Flair Homes Energy Demo/CHBA Flair Mark XIV Project. Four of the structures were built to the R-2000 Standard while the fifth was a control structure built to conventional standards. Sound pressure levels generated by the heating and ventilation systems were measured and compared to recommended indoor design goals for ventilation system sound control. Measurements were also made of the attenuation of outdoor noise, generated with a gas-powered lawnmower, by the different building envelope types in the houses.

The study found that sound pressure levels generated by mechanical systems ranged significantly between houses and, on average, exceeded the acoustical design goal for the "worst case" room which was located directly above the mechanical system. This raised the concern that homeowners may defeat the ventilation system using the "off" switch as a means of controlling noise generated by the mechanical system and thereby lose the benefits of the mechanical ventilation system.

Windows were found to be a major pathway for noise transmission across the building envelope. This suggested that noise transmission across the envelope would be independent of the wall type if the wall or room contained windows. It was concluded that from a builder's perspective, windows should be selected which have low air leakage characteristics since a significant portion of airborne noise transmission can occur along the same pathways as air leakage. Measures should also be taken to minimize air leakage, and hence sound transmission, between the window frame and the rough opening. Finally, windows should be located, as much as possible, away from significant sources of outdoor noise.

Ductwork which ran through exterior walls was also found to create acoustic "weak spots" through which sound was readily transmitted. To control the transmission of outdoor noise, builders were advised to minimize ductwork penetrations on walls which face major sources of noise.

RÉSUMÉ

Des mesures des niveaux sonores ont été prises dans cinq maisons inoccupées et sans ameublement construites à Winnipeg dans le cadre du projet Flair Mark XIV de Flair Homes Energy Demo et de l'ACCH. Quatre de ces maisons ont été construites en conformité de la norme R-2000 tandis que la cinquième était de construction traditionnelle. Les niveaux de pression acoustique produits par les installations de chauffage et de ventilation ont été mesurés et comparés aux objectifs initiaux d'atténuation du bruit des installations de ventilation. Des mesures ont aussi été prises de l'atténuation des bruits extérieurs produits par une tondeuse à essence grâce à différentes enveloppes de bâtiment.

L'étude indique que les niveaux de pression acoustique produits par les installations mécaniques variaient considérablement d'une maison à une autre et que, en moyenne, ils dépassaient la limite de calcul recommandée à l'intérieur de la pièce la plus exposée, qui était celle directement au-dessus des installations mécaniques. Ces conclusions laissent entrevoir un problème : les occupants pourraient arrêter la ventilation pour éliminer le bruit produit par les installations mécaniques, sacrifiant ainsi les avantages de la ventilation mécanique.

Les fenêtres constituent l'un des principaux trajets de transmission du son à travers l'enveloppe du bâtiment, ce qui laisse entendre que cette transmission est indépendante du mode de construction du mur si le mur ou la pièce comporte des fenêtres. Les analystes ont conclu que les constructeurs devraient choisir des fenêtres à faible perméabilité à l'air puisqu'une partie importante de la transmission des sons aériens se produit par les mêmes trajets que les fuites d'air. Des mesures doivent aussi être prises pour réduire au minimum les fuites d'air, et par conséquent la transmission du son, par les joints entre le dormant des fenêtres et l'encadrement brut. Enfin, les fenêtres devraient, dans la mesure du possible, être situées à distance des sources extérieures très bruyantes.

Les conduits traversant les murs extérieurs constituent également des "points faibles" du point du vue acoustique puisque les sons s'y transmettent facilement. Pour éviter la transmission des bruits extérieurs, il est recommandé aux constructeurs de réduire au minimum ces pénétrations dans les murs faisant face à des sources très bruyantes.

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

Sound is an important parameter which affects the quality of the indoor house environment. When the sound intensity, or its other characteristics such as tonal patterns, frequency distribution or variation with time reach certain levels, a homeowner will interpret the environment as "noisy". As a result, designers need to consider those factors which affect sound levels in a house. Basically, there are two sources of sound to consider - that which is generated externally (vehicle traffic, aircraft, outdoor appliances, etc.) and that originating from operation of the building's mechanical system. The first is affected by the building envelope (specifically its sound transmission characteristics) and the second by the sound generation patterns of the motors, blowers, compressors, and other devices which make up the mechanical system.

This report describes a study which was carried out to investigate these issues under field conditions. The work was performed as part of the Flair Homes Energy Demo/CHBA Flair Mark XIV Project.

1.2 THE FLAIR HOMES ENERGY DEMO/CHBA FLAIR MARK XIV PROJECT

The Flair Homes Energy Demo/CHBA Flair Mark XIV Project is a demonstration with three objectives:

1. To demonstrate and evaluate the performance of various low energy building envelope systems.
2. To demonstrate and evaluate the performance of various residential mechanical systems with particular emphasis on ventilation systems.
3. To transfer the knowledge gained in the project to the Canadian home building industry.

In addition, the project is structured to support the R-2000 Home Program funded by Energy, Mines and Resources Canada and administered by the Canadian Home Builders Association. The project acquired the Mark XIV designation when a substantial portion of the research priorities identified by the Technical Research Committee of the CHBA in 1983/84 was incorporated into the project.

Support for the project has been provided by Energy, Mines and Resources Canada under the Energy Demo Program and by Manitoba Energy and Mines under the Manitoba/Canada Conservation and Renewable Energy Demonstration Agreement (CREDA). Project management is the responsibility of Flair Homes (Manitoba) Ltd. Monitoring of the project houses is the responsibility of UNIES Ltd. and will continue until the spring of 1989.

To meet the project objectives, 20 houses employing various envelope and mechanical systems were constructed in 1985 and 1986 in the Genstar Development Co. Lakeside Meadows subdivision of Winnipeg. The houses were built by Flair Homes (Manitoba) Ltd. using two of their standard floor plans. They are divided into 10 pairs, with each pair having a different combination of envelope and mechanical systems. Conservation levels range from those of conventional houses to those which meet or exceed the R-2000 Standard. A summary description of the project houses is shown in Table 1 and more information on their design and construction is contained in Reference 1.

1.3 OBJECTIVES

The objectives of the work described in this report were as follows:

1. To measure the sound pressure (noise) levels generated by the heating and ventilation systems installed in four of the project houses plus one other conventional, non-project house and to evaluate these levels relative to recommended indoor design goals for ventilation system sound control.
2. To measure the attenuation of outdoor noise (generated using a lawnmower) by the different building envelope types in these same houses.

SECTION 2

TEST HOUSES

2.1 HOUSE DESCRIPTIONS

The sound level survey was conducted in four houses of the Flair Homes Energy Demo/CHBA Flair Mark XIV Project plus a control house, as described below. The four project houses were architecturally-identical bungalows with the same floor plans, situated on the same street while the control house was a slightly smaller bungalow located on an adjacent street. All were complete but unoccupied with no furnishings at the time of the test. Mechanical systems were in a contractor-delivered state.

1. House #20 - Airtight Drywall Approach (ADA) envelope construction with a CES van EE 2000 Heat Recovery Ventilator system using high sidewall supply registers and baseboard electric heating. Wall-to-wall carpets installed on the main floor, unfinished basement with interior insulation. Triple-glazed awning windows in the bedrooms and kitchen and non-operating units in the remaining areas on the main floor.

2. House #13 - Fiberglas Canada Inc. Low Energy House System envelope construction with a CES van EE 2000 Heat Recovery Ventilator system using high sidewall supply registers integrated through an indirect connection to a single speed, belt drive electric forced air furnace. Wall-to-wall carpets installed on main floor, unfinished basement with no interior insulation. Triple-glazed awning windows in the bedrooms and kitchen with awning and non-operating units in the remaining areas on the main floor.

3. House #18 - Double wall construction with Nilan heat pump air-to-air Heat Recovery Ventilator system using high sidewall supply registers and baseboard electric heating. Wall-to-wall carpets installed on main floor, unfinished basement with interior insulation. Triple-glazed casement windows in the bedrooms, awning unit in the kitchen and casement and non-operating units in the remaining areas of the main floor.

4. House #15 - Double wall construction with Peach heat pump heating, cooling and ventilation system (forced air) using high sidewall supply and low wall return registers. Supplemental exhaust fan drawing from bathroom and kitchen and exhausting through header. Wall-to-wall carpets installed on main floor, unfinished basement with interior insulation. Triple-glazed casement windows in the

bedrooms, awning unit in the kitchen and casement and non-operating units in the remaining areas of the main floor.

5. Control - Conventional 38x140 (2x6) frame construction with a single speed, belt drive natural gas forced air furnace using floor mounted supply registers. Wall-to-wall carpets installed on main floor, finished basement with interior insulation. Triple-glazed awning windows in the bedrooms and casements and non-operating units in the remaining areas of the main floor.

No sound mufflers were installed on any of the mechanical systems. Canvas isolation boots were installed on the ductwork in House #15 to reduce vibration transfer from the mechanical system to the ductwork. None of the other houses were similarly equipped. House exteriors were stucco-covered on three sides. All windows were produced by the same manufacturer and used 13 mm (½") air spaces between panes. The windows were judged to have relatively low air leakage based on the airtightness performed on the four project houses.

The sound level survey provided a comparison of four of the building envelope types as well as four of the mechanical systems used in the Flair project. The project houses containing the Habitair, central exhaust and point source exhaust ventilation systems were not available for testing.

SECTION 3

PROCEDURES

3.1 MEASUREMENTS

Sound pressure levels were measured using a B & K Type 2203 precision sound level meter (SLM) and a B & K Type 1613 octave filter set. The SLM was calibrated before and after each series of measurements. At each test condition and measurement location, single measurements of the A-weighted sound pressure level (dBA) and the octave band levels (dB) were recorded. The A-weighted sound level is a logarithmic summation of sound pressure levels at all frequencies. However, to approximate how a sound is perceived by the human ear, the weighting network de-emphasizes the low frequency portions of the noise spectrum, automatically compensating for the lower sensitivity of the human ear to low frequency sounds (see Appendix B).

With respect to the operation of the ventilation and/or heating (mechanical) system, sound pressure levels were measured in the basement approximately 1 m (3 ft.) from the operating equipment and in the bedroom directly above the mechanical equipment. The specific operating conditions of each mechanical system are described in Appendix A along with the tabulated sound pressure levels.

To evaluate outdoor noise attenuation by the different envelope systems, two cursory tests were conducted using a Sears Craftsman gas-powered lawnmower as a noise generator. For the first test, the mower was operated at a stationary position in the backyard at a distance of 4 m (13 ft.) from the master bedroom window. Sound pressure levels were measured adjacent to the bedroom wall on the outside and 2 m (7 ft.) from the bedroom window on the inside.

For the second envelope attenuation test, the mower was operated approximately 1 m (3 ft.) from the exterior wall of the bathroom. Sound pressure levels then were measured adjacent to the wall on the outside and 1 m (3 ft.) from the wall inside the bathroom. The bathroom did not contain a window. The difference between the measured sound pressure level on the outside and the level on the inside represented the attenuation (reduction) of sound across the envelope system.

Since air leakage pathways are known to affect the attentuation characteristics of building envelopes, airtightness tests were performed on the four project houses. No airtightness tests was performed on the control house.

SECTION 4

RESULTS AND DISCUSSION

4.1 MECHANICAL SYSTEMS

The results of the sound pressure level measurements for the test conditions are tabulated in Appendix A. The fundamentals of sound measurement and indoor design goals for mechanical systems are reviewed in Appendix B. Airtightness tests results are shown in Table 2.

A comparison of the sound pressure levels measured on the A-weighted scale and generated by the mechanical systems is presented in Table 1. Measuring noise levels on the A-weighted scale has the advantage that the measured value correlates well with human judgement of relative loudness. It has the disadvantage of not correlating well with human judgement of relative noisiness or the subjective "quality" of sound (e.g. the annoyance of a single frequency tone). Thus Noise Criteria (NC) Curves have been developed to define the limits that an octave-based spectrum (i.e. frequency breakdown) of a noise source must not exceed to achieve a level of occupant acceptance. ASHRAE (Ref. 2) recommends an NC level of 25 to 30 as a design goal for the noise levels generated by the mechanical system in private residences (see Table 19, Appendix B). An NC level of 30 in the living spaces was considered the goal for this survey.

For each noise measurement location and operating condition of the mechanical systems, NC levels were determined using the measured octave-band levels tabulated in Appendix A based on the NC curves in Appendix B. For each test condition, the measured octave band sound pressure levels were plotted on the NC curves. The corresponding NC level was established by the NC curve that falls above all octave band levels. The resulting NC levels are included with the summary data in Table 3. NC levels associated with mechanical equipment operation ranged from 17 to 36 in the bedroom directly above the operating equipment, representing noise levels both below and above the ASHRAE design goal.

Interestingly, the same type of equipment, a CES van EE 2000 HRV, generated the highest bedroom NC level (in House #20) and the lowest level

TABLE 2

AIRTIGHTNESS TEST RESULTS

	NLA (cm^2/m^2)	ac/hr_{50}
House #20	0.30	0.71
House #13	0.36	0.84
House #18	0.23	0.42
House #15	0.65	1.33

Notes

1. Conducted in accordance with CAN/CGSB-149.10-17.
2. NLA = Normalized Leakage Area.
3. ac/hr_{50} = air changes per hour at 50 Pascals.

Table 3: Sound Pressure Levels (SPL) and Calculated Noise Criteria (NC) Levels Associated with the Operation of the Ventilation and Heating Systems.

SYSTEM DESCRIPTION	TEST CONDITION	MEASURED SPL (dBA) in:		CALCULATED NC LEVEL (dB) for:	
		Basement	Bedroom	Basement	Bedroom
House #20: van EE 2000 and baseboard heating.	1. HRV on "high" speed	48	39	42	36
	2. HRV on "continuous" speed	41	33	37	27
House #13: van EE 2000 with forced air electric heating.	1. HRV on "high" (furnace "off")	51	32	47	22
	2. HRV on "continuous" speed (furnace "off")	44	26	41	17
	3. Furnace fan "on" (HRV "off")	47	36	40	30
	4. HRV on "high" & furnace fan "on"	53	38	48	30
	5. HRV on "cont" & furnace fan "on"	49	37	45	29
House #18: Nilan heat pump HRV and baseboard heating.	1. Nilan fans on "high" speed (compressor "off")	51	36	46	33
	2. Nilan fans on "low" speed (compressor "off")	46	34	43	27
House #15: Peach heat pump (forced air heating, cooling & ventilating)	1. Compressor "on" & fans on "high"	52	40	45	35
	2. Compressor "off" & fans on "low"	50	35	44	35
Control Gas forced air heating.	1. Furnace fan operating on single speed (control test)	54	40	54	34

(in House #13). A review of the octave-band data (Appendix A) indicates there was a significant difference in the sound levels at 125 Hz (cycles per second) for the two HRV's. Notice that House #13 had no insulation on the interior of the basement walls at the time of the measurements which would likely have affected the basement levels which in turn may have affected the main floor levels.

The Nilan heat pump HRV ventilation system produced an NC level of 33 in the bedroom with the fans on high speed and a level of 27 with the fans on low speed. (The control system for the heat pump had not been commissioned and therefore no test was conducted with the compressor operating).

The Peach heat pump, forced air heating, cooling and ventilation system produced an NC level of 35 in the bedroom with the fans on high speed and with the compressor running. The same level was recorded with the unit on low speed. In this mode, the compressor and the outdoor air fan are off. This suggests that the indoor air fan, not the outdoor air fan or compressor, was the primary source of noise.

The forced air furnace in House #13 met the ASHRAE recommended design goal with an NC level of 30 while the furnace in the Control House generated an NC level of 34 in the bedroom above the mechanical system.

It should be stressed that results for specific pieces of equipment should not be regarded as definitive for that particular make and model because of the possibility of experimental error and/or non-representativeness of the equipment encountered in the houses.

4.2 ENVELOPE SYSTEMS

The results of the envelope attenuation tests are summarized in Table 4 and Figure 1. The first set of tests attempted to evaluate the reduction of outdoor noise across the bedroom wall as a function of envelope type. However, it was found that the attenuation across the bedroom wall was very similar from one house to the other, suggesting that the bedroom windows were the dominant path of noise transmission and that the reduction of sound levels from the outside to the bedroom would be independent of the wall section type if the wall contained a window.

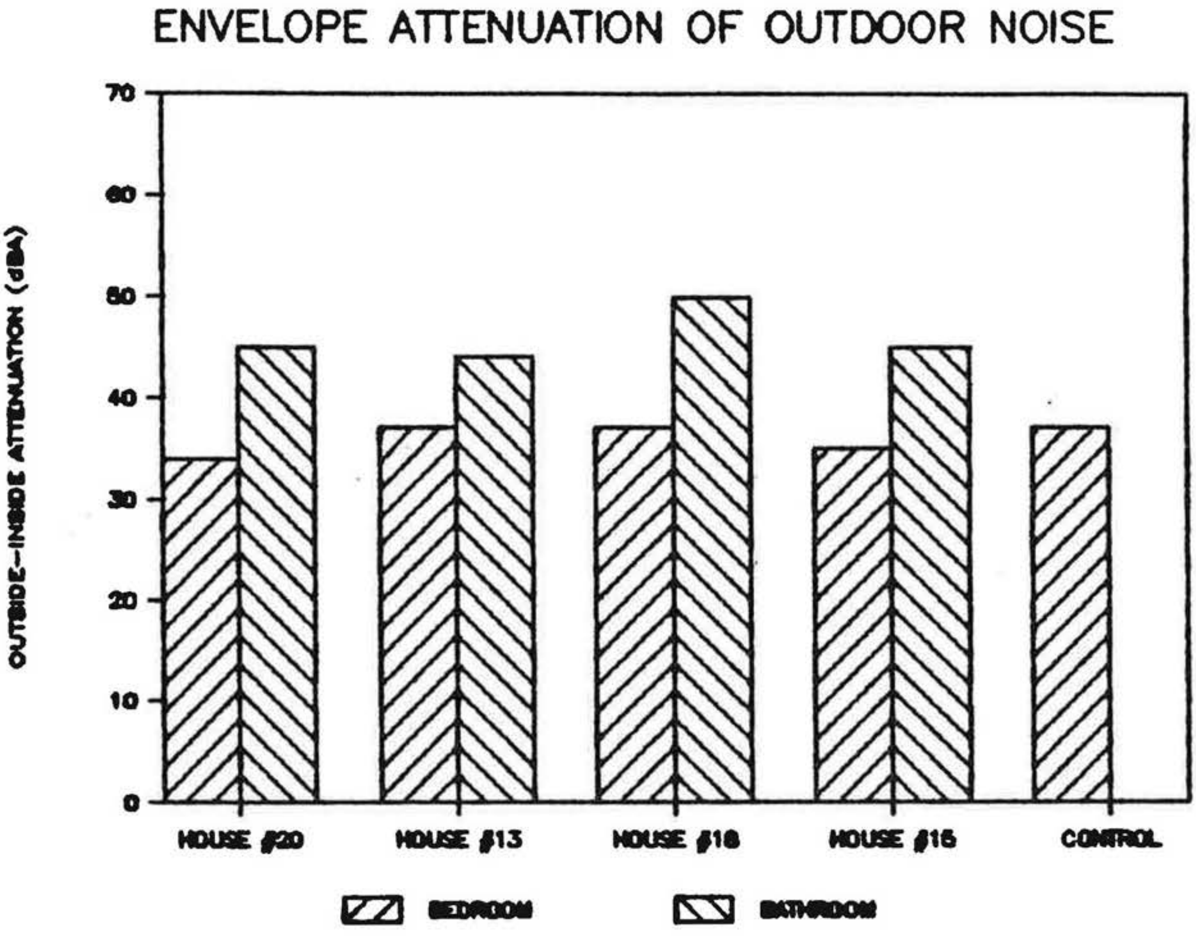
Table 4: Envelope Attenuation of Outdoor Noise (Lawnmower-generated)

HOUSE/ENVELOPE DESCRIPTION	TEST LOCATION	OUTSIDE SPL (dBA)	INSIDE SPL (dBA)	ATTENUATION (OUTSIDE-INSIDE) (dBA)
House #20:	Bedroom	78	44	34
Airtight Drywall Approach (ADA) construction	Bathroom	85	40	45
House #13:	Bedroom	78	41	37
FCI LEHS wall construction	Bathroom	85	41	44
House #18:	Bedroom	78	41	37
Double wall construction	Bathroom	85	35	50
House #15:	Bedroom	78	43	35
Double wall construction	Bathroom	85	40	45
Control, conventional 38x140 (2x6) frame construction	Bedroom	79	42	37

NOTES

1. All windows triple-glazed.

FIGURE 1



ENVELOPE ATTENUATION OF OUTDOOR NOISE
OUTSIDE-INSIDE ATTENUATION (dBA)
70
60
50
40
30
20
10
0
HOUSE #20
HOUSE #13
HOUSE #18
HOUSE #16
CONTROL
BEDROOM
BATHROOM

In the second test, designed to identify differences in the noise attenuating characteristics of the wall systems exclusive of windows, the lawnmower was operated beside the windowless bathroom wall. Sound pressure level measurements were made on the outside and on the inside of the bathroom with the bathroom door closed. Attenuations of 45 dBA and 44 dBA were measured for Houses #20 and #13 respectively. As anticipated, an increase in attenuation was noted for House #18 which used double wall construction. However, the 5 dBA performance advantage of the double wall system was lost in House #15 because the bathroom exhaust ductwork provided a direct sound path to the outside of the house adjacent to the operating lawnmower.

Note that sound pressure level data at the lower frequencies may be subject to error caused by the formation of standing waves, a phenomena that occurs when the wavelength of sound approaches the dimensions of an enclosure.

SECTION 5

CONCLUSIONS

5.1 CONCLUSIONS

The results of this survey do not represent an exhaustive study of sound levels in the demonstration houses. However, they provide valuable insights into the "noise" characteristics of the houses and form the basis for a data base on noise levels in R-2000 housing. Although the scope of the investigation was limited to a single site survey, the test protocols were rigorously applied on houses of essentially identical architectural and floor plan configurations with no furnishings to obscure the results.

1. The sound pressure levels generated by the mechanical systems ranged significantly between houses and, on average, exceeded the acoustical design goal for the room which was located directly above the mechanical system. This raised the concern that homeowners may use the "off" switch as a means of controlling noise generated by mechanical systems and thereby lose the benefits of a mechanical ventilation system. Only one of the five mechanical installations met the goal of an NC level less than 30 under all operating conditions in the "worst-case" room. When operated under the recommended continuous or low fan-speed condition, three of the four ventilation systems met the NC goal. Of the two furnaces tested (without the ventilation system operating) only one met the NC goal. Research and training initiatives should continue to emphasize the importance of mechanical system noise control.

2. Windows were found to be a major pathway for noise transmission across the building envelope. This suggested that noise transmission across the envelope would be independent of wall type if the wall or room contained a window. From a builder's perspective, windows should be selected which have low air leakage characteristics since a significant portion of airborne noise tranmission can occur along the same pathways as air leakage. They should also be installed using techniques to reduce air leakage, and hence sound transmission, between the window frame and the rough opening. Finally, windows should be located, as much as possible, away from significant sources of outdoor noise.

3. Ductwork which ran through exterior walls was also found to create acoustic "weak spots" through which sound was readily transmitted. To control the transmission of outdoor noise, it was concluded that builders should minimize ductwork penetrations on walls which face major sources of noise such as streets or commercial establishments.

REFERENCES

1. Proskiw, G. and Beckman, J., UNIES Ltd.; "Description of Project Houses"; 1988.

2. ASHRAE Systems Handbook, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.; 1984.

APPENDIX A

Measured Sound Pressure Levels (dBA), Octave Band Levels (dB) and Calculated Noise Criteria (NC) Rating for Described Test Conditions and Sound Measurement Locations.

TABLE A1

HOUSE NUMBER AND DESCRIPTION: House #20 - ADA Construction with CES van EE 2000 HRV System and Baseboard Heating

MEASUREMENT LOCATION AND TEST CONDITION	OCTAVE BAND LEVELS (dB) for CENTRE FREQUENCIES (Hz)										MEASURED dBA	CALCULATED NC
	31	63	125	250	500	1000	2000	4000	8000	16000		
A. MECHANICAL SYSTEM 1. HRV operative on high speed;												
i) basement	52	52	58	43	41	43	38	36	28	14	47.5	42
ii) bedroom	60	52	53	36	30	29	24	22	15	14	39	36
2. HRV operating on recommended continuous speed;												
i) basement	59	49	51	40	36	38	31	28	19	10	41	37
ii) bedroom	62	44	46	31	23	23	12	11	10	9	33	27
3. Background level in bedroom.											20	

TABLE A1 (con't)

House #20

MEASUREMENT LOCATION AND TEST CONDITION	OCTAVE BAND LEVELS (dB) for CENTRE FREQUENCIES (Hz)										MEASURED dBA	REDUCTION dBA
	31	63	125	250	500	1000	2000	4000	8000	16000		
B. <u>ENVELOPE ATTENUATION</u> 1. Sound levels produced by lawnmower located 4 m (13 ft.) from bedroom wall;												
i) 1.2 m (4 ft.) from wall (outside)		67	79	80	72	72	70	70	66	61	78	78-44=34
ii) 2 m (7 ft.) from bedroom window (inside)		47	52	52	36	28	26	24	16	11	44	
2. Sound levels produced by lawnmower located beside bathroom wall;												
i) 1.2 m (4 ft.) from bathroom wall (outside)	81	79	85	83	80	79	76	75	72	63	85	85-40=45
ii) 1.2 m (4 ft.) from bathroom wall (inside)	50	50	46	47	34	28	15	13	9	9	40	

TABLE A2

HOUSE NUMBER AND DESCRIPTION: House #13 - FCI LEHS Construction with CES van EE 2000 HRV and Electric Forced Air Heating

MEASUREMENT LOCATION AND TEST CONDITION	OCTAVE BAND LEVELS (dB) for CENTRE FREQUENCIES (Hz)										MEASURED dBA	CALCULATED NC
	31	63	125	250	500	1000	2000	4000	8000	16000		
A. MECHANICAL SYSTEM 1. HRV operative on high speed (furnace fan off);												
i) basement	56	52	52	45	46	48	43	36	30	16	51	47
ii) bedroom	64	47	42	33	26	22	14	10	9	9	32	22
2. HRV operating on "continuous" speed (furnace fan off);												
i) basement	60	46	43	38	40	42	34	26	18	10	44	41
ii) bedroom	58	42	38	28	21	17	10	9	9	8	26	17
3. Furnace fan operating (HRV off);												
i) basement	48	46	52	45	45	41	36	28	18	10	47	40
ii) bedroom	42	41	48	40	33	30	24	14	10	9	36	30

TABLE A2 (con't)

House #13

MEASUREMENT LOCATION AND TEST CONDITION	OCTAVE BAND LEVELS (dB) for CENTRE FREQUENCIES (Hz)										MEASURED dBA	CALCULATED NC
	31	63	125	250	500	1000	2000	4000	8000	16000		
4. Furnace fan operating with the HRV on high;												
i) basement	61	54	55	48	49	49	44	37	29	15	53	48
ii) bedroom	55	48	48	38	34	31	26	15	10	9	38	30
5. Furnace fan operating with the HRV on "continuous" speed;												
i) basement	62	50	52	46	46	46	39	31	21	10	49	45
ii) bedroom	63	46	47	38	34	30	25	15	10	9	37	29
6. Background												
i) bedroom	40	33	24	15	9	8	8	10	7	8	18	

TABLE A2 (con't)

House #13

MEASUREMENT LOCATION AND TEST CONDITION	OCTAVE BAND LEVELS (dB) for CENTRE FREQUENCIES (Hz)										MEASURED dBA	REDUCTION dBA
	31	63	125	250	500	1000	2000	4000	8000	16000		
B. <u>ENVELOPE ATTENUATION</u> 1. Lawnmower located 4 m (13 ft.) from bedroom window in backyard;												
i) 1.2 m (4 ft.) from wall (outside)	69	67	77	78	74	70	71	67	62	53	78	78-41=37
ii) 2 m (7 ft.) from bedroom window (inside)	54	55	54	44	34	27	25	18	12	10	41	
2. Lawnmower located beside bathroom wall;												
i) 1.2 m (4 ft.) from wall (outside)	80	76	85	84	82	80	77	74	72	63	85	85-41=44
ii) 1.2 m (4 ft.) from wall (inside)	54	51	54	44	34	28	20	18	10	9	41	

TABLE A3

HOUSE NUMBER AND DESCRIPTION: House #18 - Double Wall Construction with Nilan Heat Pump HRV System and Electric Baseboard Heating

MEASUREMENT LOCATION AND TEST CONDITION	OCTAVE BAND LEVELS (dB) for CENTRE FREQUENCIES (Hz)										MEASURED dBA	CALCULATED NC
	31	63	125	250	500	1000	2000	4000	8000	16000		
A. MECHANICAL SYSTEM 1. Ventilation fans on high speed (heat pump compressor off);												
i) basement	47	48	49	47	44	45	46	34	31	23	51	46
ii) bedroom	40	41	39	35	29	32	32	11	9	9	36	33
2. Ventilation fans on low speed (compressor off);												
i) basement	42	43	58	42	37	40	32	25	23	16	46	43
ii) bedroom	40	34	42	31	24	29	19	10	9	9	34	27
3. Background												
i) bedroom	44	30	28	19	12	10	9	9	9	9	18	

TABLE A3 (con't)

House #18

MEASUREMENT LOCATION AND TEST CONDITION	OCTAVE BAND LEVELS (dB) for CENTRE FREQUENCIES (Hz)										MEASURED dBA	REDUCTION dBA
	31	63	125	250	500	1000	2000	4000	8000	16000		
B. ENVELOPE ATTENUATION 1. Lawnmower located 4 m (13 ft.) from bedroom window in backyard;												
i) 1.2 m (4 ft.) from wall (outside)	70	67	77	80	76	72	70	67	62	54	78	78-41=37
ii) 2 m (7 ft.) from bedroom window (inside)	48	42	47	48	34	30	26	19	10	9	41	
2. Lawnmower located beside bathroom wall;												
i) 1.2 m (4 ft.) from wall (outside)	77	79	85	82	81	79	77	74	72	65	85	85-35=50
ii) 1.2 m (4 ft.) from wall (inside)	53	50	51	34	32	24	13	10	9	9	35	

TABLE A4

HOUSE NUMBER AND DESCRIPTION: House #15 - Double Wall Construction with a Peach Integrated Heat Pump Heating, Cooling and Ventilation System (Forced Air)

MEASUREMENT LOCATION AND TEST CONDITION	OCTAVE BAND LEVELS (dB) for CENTRE FREQUENCIES (Hz)										MEASURED dBA	CALCULATED NC
	31	63	125	250	500	1000	2000	4000	8000	16000		
A. MECHANICAL SYSTEM 1. Peach compressor operating with fans on high speed;												
i) basement	58	58	55	53	49	46	42	39	32	20	52	45
ii) bedroom	55	50	49	45	32	24	16	13	10	9	40	35
2. Peach compressor "off" and fans operating on low speed;												
i) basement	55	54	53	51	46	45	39	36	29	17	50	44
ii) bedroom	48	44	47	45	30	22	14	13	10	9	35	35

TABLE A4 (con't)

House #15

MEASUREMENT LOCATION AND TEST CONDITION	OCTAVE BAND LEVELS (dB) for CENTRE FREQUENCIES (Hz)										MEASURED dBA	REDUCTION dBA
	31	63	125	250	500	1000	2000	4000	8000	16000		
B. <u>ENVELOPE ATTENUATION</u> 1. Lawnmower located 4 m (13 ft.) from bedroom window in backyard;												
i) 1.2 m (4 ft.) from wall (outside)	70	69	81	78	75	73	70	68	61	54	78	78-43=35
ii) 2 m (7 ft.) from bedroom window (inside)	48	48	48	52	32	28	24	19	10	9	43	
2. Lawnmower located beside bathroom wall;												
i) 1.2 m (4 ft.) from wall (outside)	78	77	85	83	80	80	77	75	72	63	85	85-40=45
ii) 1.2 m (4 ft.) from wall (inside)	50	51	52	41	38	32	15	10	10	10	40	

TABLE A5

HOUSE ADDRESS AND DESCRIPTION: Control - Conventional 38x140 (2x6) Frame Construction with Gas Forced Air Heating

MEASUREMENT LOCATION AND TEST CONDITION	OCTAVE BAND LEVELS (dB) for CENTRE FREQUENCIES (Hz)										MEASURED dBA	CALCULATED NC
	31	63	125	250	500	1000	2000	4000	8000	16000		
A. MECHANICAL SYSTEM 1. Furnace fan operating on single speed setting;												
i) basement	66	68	66	54	50	48	44	39	35	26	54	54
ii) bedroom	57	58	51	43	34	29	24	15	10	9	40	34
B. ENVELOPE ATTENUATION 1. Lawnmower located 4 m (13 ft.) from bedroom window in backyard;												REDUCTION dBA
i) 1.2 m (4 ft.) from wall (outside)	70	69	77	77	78	73	73	68	63	53	79	79-42=37
ii) 2 m (7 ft.) from bedroom window (inside)	48	46	43	47	41	29	28	21	11	9	42	

APPENDIX B

SOUND MEASUREMENT FUNDAMENTALS

Reference:

ASHRAE Handbook, 1984, Systems.

ACOUSTICAL DESIGN GOALS

The recommended acoustical design goal for air-conditioning systems is the achievement of a level of background sound that is unobtrusive in quality, and low enough in level that it does not interfere with the occupancy requirements of the space being served. It is important to recognize that the degree of occupancy satisfaction achieved with a given level of background sound is multidimensional. To be unobtrusive, it should have the following properties:

1. A balanced distribution of sound energy over a broad frequency range.

2. No audible tonal characteristics such as a whine, whistle, hum or rumble.

3. No noticeable time-varying levels from beats or other system-induced aerodynamic instability.

In other words, the background sound should be steady in level, bland in character and free of identifiable machinery noises.

Under carefully controlled experimental conditions, humans can detect small changes in sound level. But the human reaction describing halving or doubling of loudness requires changes in sound pressure level on the order of 10 dB. For broadband sounds, 3 dB is a minimum perceptible change. This means that halving the power output of the source results in a barely noticeable change in sound pressure level, and the power output must be reduced by a factor of 10 before humans determine that loudness has been halved. Subjective changes are shown in the following table:

Subjective Effect of Changes in Sound Pressure Level, Broadband Sounds

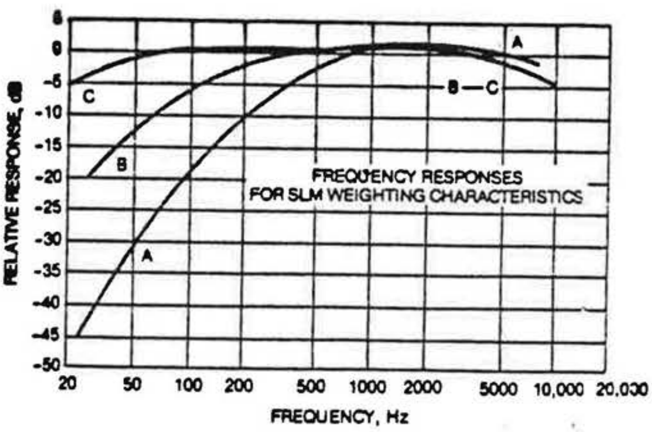
Change in Sound Pressure Level	Apparent Change in Loudness
3 dB	Just noticeable
5 dB	Clearly noticeable
10 dB	Twice (or half) as loud

A-WEIGHTED SOUND LEVEL

The A-Weighted Sound Level (dBA) scale is one of the most widely used methods of stating design goals in terms of a single number, but its usefulness is limited because it gives no information on spectrum content needed for engineering. The measuring method is simple since the A-Scale sound level is obtained from one reading on a simple instrument. The standard sound level meter includes an electronic weighting network that de-emphasizes the low frequency portions of the noise spectrum, automatically compensating for the lower sensitivity of the human ear to low frequency sounds. Figure 8 shows the characteristic of the A-weighting network.

The A-weighted sound pressure level has the advantage of identifying the desirable level as a single-valued number that correlates well with human judgment of relative loudness. However, it has the disadvantage of not correlating well with human judgment of the relative noisiness or the subjective quality of the sound.

The A-weighted level comparison is best used with noises that sound alike but differ mainly in level. It should not be used for comparison of sounds with distinctly different spectral characteristics. In other words, two sounds at the same dBA level, but with different spectral content, may be judged differently by the listener for an acceptable background should in his environment. One of these noises might be completely acceptable, while the other could be objectionable because its spectrum shape resulted in a sound which was rumbly, hissy or tonal in character.



Curves Showing A, B and C-Weighting Networks

NC CURVES

The NC (Noise Criteria) Curves (Fig. 9) have been widely used for many years. In practice, these curves define the limits that the octave-band spectrum of a noise source must not exceed to achieve a level of occupant acceptance. For example, an NC-35 design goal is commonly used for private offices; the background noise level meets this goal provided no portion of its spectrum lies above the designated NC-35 curve.

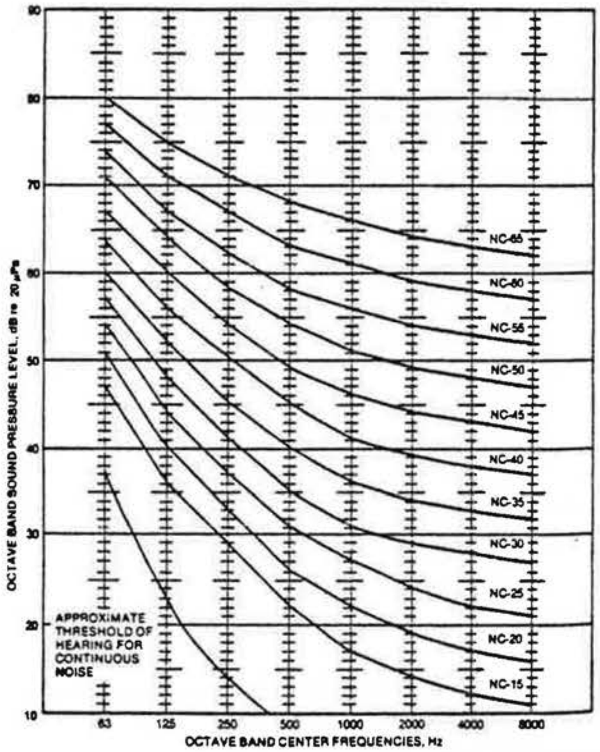


Fig. 11 NC (Noise Criteria) Curves for Specifying the Design Level in Terms of the Maximum Permissible Sound Pressure Level for Each Frequency Band

Table 19 Recommended Indoor Design Goals for Air-Conditioning System Sound Control[a]

(Note: These are for *unoccupied* spaces, with all systems operating.)

Type of Area	Recommended RC or NC Criteria Range
1. Private residences	25 to 30
2. Apartments	30 to 35
3. Hotels/motels	
a. Individual rooms or suites	30 to 35
b. Meeting/banquet rooms	30 to 35
c. Halls, corridors, lobbies	35 to 40
d. Service/support areas	40 to 45
4. Offices	
a. Executive	25 to 30
b. Conference rooms	25 to 30
c. Private	30 to 35
d. Open-plan areas	35 to 40
e. Computer/business machine areas	40 to 45
f. Public circulation	40 to 45
5. Hospitals and clinics	
a. Private rooms	25 to 30
b. Wards	30 to 35
c. Operating rooms	25 to 30
d. Laboratories	30 to 35
e. Corridors	30 to 35
f. Public areas	35 to 40
6. Churches	25 to 30[b]
7. Schools	
a. Lecture and classrooms	25 to 30
b. Open-plan classrooms	30 to 35[b]
8. Libraries	30 to 35
9. Concert halls	b
10. Legitimate theaters	b
11. Recording studios	b
12. Movie theaters	30 to 35

[a]Design goals can be increased by 5 dB when dictated by budget constraints or when noise intrusion from other sources represents a limiting condition.
[b]An acoustical expert should be consulted for guidance on these critical spaces.

Recommended NC design levels are listed in Table 19.