Sound Insulation and Thermal Performance Modifications: Case Study for Three Dwellings Near BWI Airport

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In 1974, the Maryland General Assembly passed the Maryland Environmental Noise Act to provide citizen protection from transportation-related noise, including minimizing of residential dwelling aircraft noise exposure. In 1987, as part of this effort, the Maryland State Aviation Administration sponsored the Pilot Residential Sound Insulation Program for 17 dwellings to determine the feasibility and associated costs of reducing aircraft noise intrusion in residential dwellings. Dwellings within the Baltimore-Washington International Airport 65-dB yearly day-night noise level noise zone contour were selected for modification. Selection of dwellings and noise reduction measurements preceded design and specification of architectural modifications to reduce noise. These modifications included replacement of windows and doors, addition of gypsumboard to walls and ceilings, and installation of new heating, ventilating, and air-conditioning systems. The sound insulation modifications resulted in greater reduction of aircraft noise intrusion by 4 to 10 dB over the previously existing noise reduction values for the three dwellings studied. The energy savings due to the sound insulation modifications resulted in a 3 to 18 percent cost reduction compared to the existing conditions. Sound insulation design goals, construction modifications, pre- and postmodification noise reduction values, and thermal performance values are described for three dwellings that were part of this program.

In 1974, the Maryland General Assembly passed the Maryland Environmental Noise Act to provide citizen protection from transportation-related noise, including minimizing of residential dwelling aircraft noise exposure. As part of this effort, Baltimore-Washington International (BWI) Airport conducted the Pilot Residential Sound Insulation Program for 17 dwellings to determine the feasibility and associated costs of reducing aircraft noise intrusion in residential dwellings. This project involved determining the number and types of houses affected, selecting representative dwellings for study, measuring the present dwelling noise reduction properties, specifying noise control modifications, and implementing construction modifications to the dwellings. For illustrative purposes, the sound insulation modifications and effects on thermal performance are examined for three of the dwellings.

RESIDENTIAL SOUND INSULATION PROGRAM OVERVIEW

The FAA considers residential land use to be compatible for areas in which the exterior noise environment does not exceed a yearly day-night noise level (DNL) of 65 dB (*1*). DNL is a cumulative noise metric in units of A-weighted decibels. The DNL metric is an annual average noise level occurring during a 24-hr period with a 10-dB penalty added to noise events occurring between 10:00 p.m. and 7:00 a.m. Dwellings located in airport noise zones with exterior levels greater than DNL 65 dB are required to have interior noise levels below DNL 45 dB.

Interior noise level design criteria for this project were selected to provide measures of long-term reaction to aircraft noise (in DNL) and of the intrusion of individual aircraft flyover noise events (in mean maximum A-weighted noise levels). Habitable portions of the dwelling were not to exceed DNL 45 dB, whereas single-event aircraft flyovers were not to exceed 60 dBA in bedrooms and television rooms and 65 dBA in all other habitable rooms in the dwelling.

To identify construction elements that were most important in determining the present level of dwelling sound insulation, the first phase of the residential sound insulation program inventoried the number and architectural characteristics of the dwellings in the airport noise zones.

Next, representative dwellings were selected from a pool of homeowner applicants, and acoustic measurements were conducted to determine existing noise insulation. Analysis was then performed for each dwelling to determine a cost-effective design solution to satisfy the sound insulation goals.

Finally, architectural drawings and specifications describing sound insulation modifications for the dwellings were prepared.

After the construction modifications were completed, acoustic measurements were performed in each dwelling to verify that program sound insulation goals were satisfied.

FACTORS AFFECTING DWELLING SOUND INSULATION PERFORMANCE

Dwelling sound insulation is influenced by local construction styles, age, and condition of the structure; aircraft flight path orientation; and dwelling-specific conditions. Figure 1 indicates the numerous paths that enable sound to enter the interior of a dwelling.

Existing architectural features are important in a dwelling's sound insulation performance. Single-story and split-level dwellings expose larger areas of living space to noise from the exterior roof path than do bilevel and two-story dwellings. Vented attic spaces provide an acoustic void between the

Wyle Laboratories, Arlington, Va., 22202.

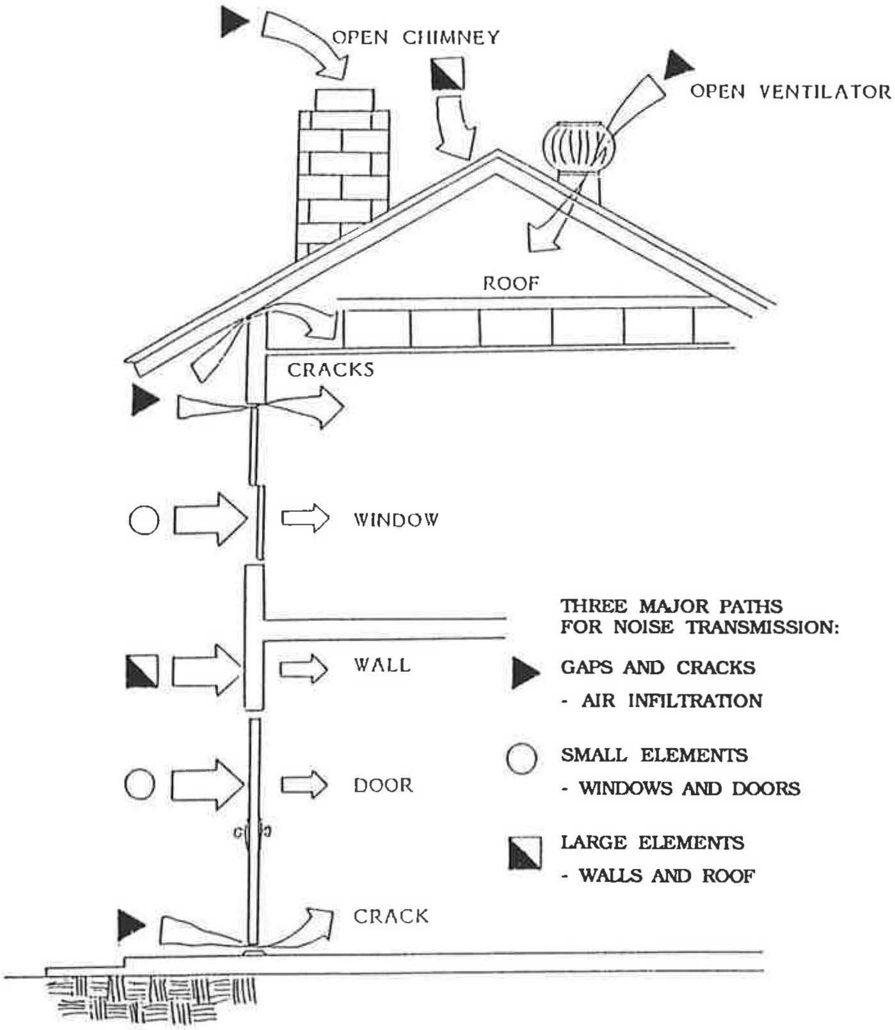

FIGURE 1 Major paths for noise transmission into dwelling interiors.

exterior and the occupied rooms that exposed ceilings and occupied attic spaces lack. Brick, stucco, and other cementitious exterior walls provide greater sound insulation than do lighter walls of wood and aluminum siding construction. Metal frame and thermal windows provide less sound insulation than wood frame and single-pane windows with exterior storm window assemblies.

Shielding of the dwelling from direct exposure to the flight path reduces the noise level at certain portions of the dwelling. Figure 2 shows measured A-weighted values of acoustical shielding at various dwelling locations. The shielding values can be reduced, typically by 5 dBA, because of sound reflections arriving at the dwelling elevation when other structures are nearby. This effect tends to be more pronounced for neighborhoods in which dwelling density is high and dwellings are closely spaced. The indicated shielding factors allow for a reduction in the required sound insulation at these portions of the dwelling.

Replacing the windows in the dwelling with acoustical windows typically does more to improve the sound insulation performance than other architectural modifications. Thermal and single-pane windows with storm assemblies provide little insulation of aircraft noise.

Exterior doors often require improved sound insulation, particularly when these doors open directly to kitchens and living rooms, which are common areas for family activities.

Interior walls and ceilings adjoining the exterior often require modifications to increase sound insulation. Typical modifications include adding gypsumboard layers directly to, or furred out from, existing surfaces with fiberglass batts installed in the cavity. Vented attic spaces are provided with 6-in. (R-19) fiberglass acoustical insulation. Exposed ceilings and occupied attic spaces normally have additional gypsumboard layers applied directly to the finished ceiling.

Table 1 presents possible modifications that can be readily adapted to residential construction and have been shown to require minimal contractor supervision to achieve successful acoustical performance.

SOUND INSULATION DESIGNS FOR THREE SELECTED DWELLINGS

Sound insulation designs were examined for three dwellings. Two of the dwellings were selected because the architectural characteristics are typical for dwellings within the DNL 65-

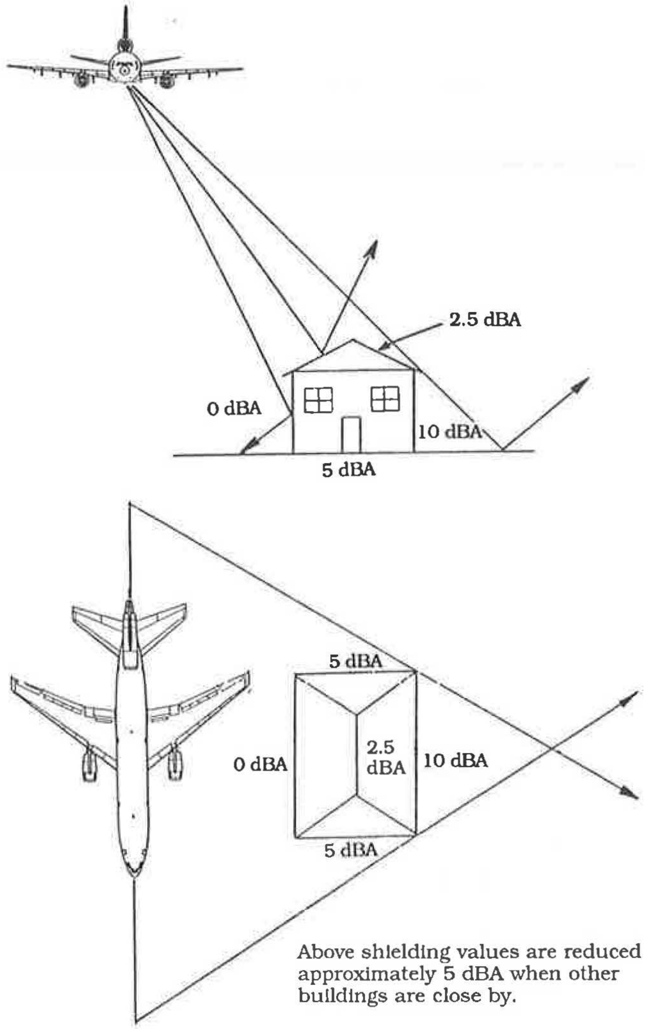

FIGURE 2 Measured values for acoustical shielding due to aircraft noise.

dB noise zone. The third dwelling was selected because of the unusual wall and heating, ventilating, and air-conditioning (HVAC) system configuration. The age, style, and construction features of the dwellings are different. Table 2 presents the existing characteristics of the three dwellings studied.

Dwelling noise reduction data were obtained as part of the initial acoustic survey by simultaneously measuring the exterior and interior sound levels due to aircraft overflights in each habitable room. At least eight room noise reduction values were obtained by taking differences between exterior and interior sound levels. Noise reduction values were then averaged to obtain a single value for each room.

Actual sound levels inside the rooms of the dwelling were obtained both in terms of the DNL and mean maximum A-weighted levels. The interior DNL values for each room were determined by subtracting each room's measured noise reduction value from the exterior DNL value as determined from the airport noise zone contours. The interior mean maximum A-weighted levels were obtained by subtracting each room's measured noise reduction value from the takeoff noise level footprint, calculated using the FAA Integrated Noise Model (INM) Computer Program, that a typical noisy aircraft (e.g., a Boeing 727–200) would produce while flying over the dwelling's location.

A computer program developed by Wyle Laboratories was used to compute the room noise reduction values on the basis of the architectural characteristics for each dwelling. This program accounts for the sound transmission paths, acoustical shielding, and room absorption. Comparing measured and computed noise reduction values resulted in differences of only 2 to 3 dB. The lower of the measured and computed values was taken as the noise reduction for each room. Table 3 presents existing and modified dwelling noise reduction and interior sound level characteristics for each room.

Selected noise reduction values were used in a computer design modification program developed by Wyle Laborato-

TABLE 1 TYPICAL CONSTRUCTION MODIFICATIONS FOR IMPROVED DWELLING SOUND INSULATION

Element	0–5 dB Noise Isolation Improvement	5–10 dB Noise Isolation Improvement	10–20 dB Noise Isolation Improvement
Windows	Seal cracks. Caulking.	Replace with STC 35 acoustic windows.	Replace with STC 40-45 acoustic windows.
Doors	Weatherstrip. Add storm doors.	Replace with STC 35 acoustic doors. Add storm doors.	Replace with STC 40 acoustic doors. Add storm doors.
Walls	Increase mass of interior surfaces.	Increase mass or resilient mounting of interior surfaces.	Resilient or furred-out mounting of new interior surfaces.
Ceiling	Add fiberglass insulation to attic space.	Increase mass of interior surfaces. Add fiberglass insulation to attic spaces.	Resilient mounting of new interior surfaces.

TABLE 2 CHARACTERISTICS OF THE DWELLINGS FOR EXISTING AND MODIFIED CONDITIONS

Element	Dwelling No. 1		Dwelling No. 2		Dwelling No. 3	
	Existing	Modified	Existing	Modified	Existing	Modified
Windows	21 single-pane, double-hung. 5 single-pane, fixed light.	15 double-hung, STC 35. 2 fixed light STC 35. 4 single-pane, double-hung. 5 single-pane, fixed light.	10 single-pane alum. sliders. 4 single-pane, fixed light.	2 double-hung STC 35. 7 double-hung, STC 40 4 single-pane, fixed light. 1 single-pane, alum. slider.	12 single-pane, double-hung, 6 single-pane, fixed light.	2 double-hung, STC 35. 7 double-hung, STC 40. 2 double-hung, STC 45. 1 double-hung, single-pane. 6 single-pane, fixed light.
Doors	3 solid-core wood. 1 single-pane glass panel.	Existing 3 solid-core wood. 1 glass panel, 1.4" lam. glass.	1 hollow-core wood. 1 panel wood.	1 solid-core STC 35. Existing 1 panel wood.	3 solid-core wood.	Existing 1 solid-core wood. 2 solid-core STC 35.
Walls	2 layers brick with plaster interior.	No modifications.	Brick veneer with 1 layer gypsumboard interior. Asphalt siding with 1 layer gypsumboard interior.	Existing brick veneer with 3 layers gypsumboard interior. Existing asphalt siding with 3 layers gypsumboard interior.	Shingle/wood clapboard with plaster interior.	Existing shingle/ wood clapboard with plaster and 2 layers gypsumboard interior.
Roof	Asphalt shingle gabled with plaster interior.	Existing asphalt shingle gabled plaster with 1 layer 5/8" gypsumboard at interior.	Asphalt shingle gable with gypsumboard interior.	No modifications.	Asphalt shingle gable with plaster interior.	No modifications.
Basement	Unfinished.	No modifications.	Unfinished.	No modifications.	Unfinished.	No modifications.
HVAC	Wood stove heat. Window air conditioning.	Gas split system HVAC (3 tons), Heat pump (2 tons), and ductwork.	Gas heating. Window air conditioning.	Gas heating and 3-ton central air conditioning.	Gas heating. Window air conditioning.	Gas heating and 3-ton central air conditioning.
Thermal	R-19 in attic knee space. No insulation in walls.	No modifications.	R-11 in attic and walls.	R-30 in attic. Existing walls.	R-6 in attic. No insulation in walls.	R-25 in attic. Existing walls.

ries. This program iteratively computes noise reduction values for various user-selected modification options and compares the result with design goals. Modifications for the three dwellings were selected from the program data base of approximately 75 construction modifications on the basis of their associated costs. This procedure allowed a cost-optimized sound insulation design to be generated for each modified room.

Existing windows in the major habitable rooms for the three dwellings were replaced with acoustical windows rated sound transmission class (STC) 35, 40, or 45. Specific window STC ratings were determined by the room's noise reduction and shielding factors. Dwelling 1, which consists of two layers of brick masonry construction, required STC 35 windows. The other two dwellings, of lightweight frame construction, required STC 40 and 45 windows. For each room, windows were selected, consistent with wall modifications, to achieve balanced acoustical design. Typically with this procedure, walls with high transmission loss values and small window dimensions require lower STC-rated windows than walls that have lower transmission loss values and larger window dimensions. In each dwelling, windows were replaced only for habitable rooms.

Because of the two layers of brick masonry forming the exterior wall construction, Dwelling 1 did not require wall modifications. This wall construction provides considerably higher transmission loss values than typical frame construction with exterior siding. Additional gypsumboard layers were applied to the exterior-facing walls for most of the habitable rooms in Dwellings 2 and 3. A single layer of ⅝-in. gypsumboard was applied to the ceiling of the occupied attic space in Dwelling 1. Additional fiberglass insulation of thickness equivalent to R−19 was provided for the vented attics in Dwellings 2 and 3. Improvements in the existing noise reduction values ranged from 4 to 10 dB to satisfy the sound insulation design goals. The average cost for the modifications was $21,730 per dwelling. Specific costs for the various modifications are presented in Table 4.

TABLE 3 MEASURED NOISE REDUCTION AND INTERIOR SOUND LEVELS FOR EXISTING AND MODIFIED CONDITION

Dwelling No.	Room	Noise Reduction		Interior Sound Level			
				Existing		Modified	
		Existing	Modified	Ldn	A-Wtd.	Ldn	A-Wtd.
1	Kitchen	26	30	49	64	45	60
	Living Room	29	34	46	61	41	56
	Master Bedroom	26	33	49	64	42	57
	Boy's Bedroom	33	38	42	57	37	52
	Girl's Bedroom	31	36	44	59	39	54
	Guest Bedroom	26	31	49	64	44	59
2	Kitchen	21	26	49	69	44	64
	Living Room	20	30	50	70	44	60
	Master Bedroom	22	31	48	68	39	59
	Boy's Bedroom	23	31	47	67	39	59
	Child's Bedroom	23	31	47	67	39	59
3	Kitchen	22	26	48	68	44	64
	Living Room	23	30	47	67	40	60
	Dining Room	22	26	48	68	44	64
	Master Bedroom	23	31	47	67	39	59
	Spare Bedroom	22	30	48	68	40	60

TABLE 4 COSTS FOR SOUND INSULATION AND HVAC MODIFICATIONS

Dwelling No.	Acoustic Windows	Other Acoustic (Drywall + Doors)	R-19 Acoustic Insulation	Demolition/ Repair Work	Elec., HVAC, & Ducting	House Total
1	$6,300	$2,330	$1,050	$0	$12,020	$21,700
2	$9,500	$3,500	0	$2,330	$6,070	$21,400
3	$7,100	$7,000	$1,110	0	$6,880	$22,090

IMPACT OF SOUND INSULATION MODIFICATIONS ON DWELLING THERMAL PERFORMANCE

The HVAC system in each dwelling was modified to provide forced-air heating and cooling, primarily so that the dwelling occupants would be able to keep the acoustic windows closed during the warmer periods of the year.

The sound insulation modifications for the three dwellings improved the thermal resistance (R-value) of the windows, doors, walls, and ceiling elements, reducing the heating and cooling loads on the dwelling envelope.

Replacing the dwelling's windows and doors and adding new caulking and weather stripping substantially reduce the perimeter air infiltration rate. This effect is more noticeable during the winter months, due to the increased stack effect. The stack effect results when the warmer inside air rises and flows out the dwelling near its top and is replaced by cooler outside air near the dwelling's base. Comparison with calculations for the existing windows, in accordance with methods given by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) (*2*) and with the acoustic window manufacturer's data, shows that the air infiltration rate for the acoustical window is one-tenth that for the existing window units.

Studies were done to determine the electricity and natural gas cost savings resulting from the sound insulation and HVAC modifications presented in Table 2. The effect of increasing the thermal insulation over that specified as part of the sound insulation modifications was also studied.

A computer program based on ASHRAE (*3*) calculation methods simulated the yearly heating and cooling loads for the existing and modified sound insulation modifications. The computer program then examined the effect of increasing the thermal insulation to meet the American Institute of Architects (AIA) recommended practice (*4*). This recommended practice calls for walls to have R–19 insulation, roofs to have R–30 insulation, and glass to be of the double-pane heat-absorbing type.

The simulated yearly utility costs for heating, cooling, and fans for no modifications and after sound insulation and thermal insulation modifications are listed in Table 5. The latter two conditions studied include HVAC modifications. Results vary according to the different dwelling sizes and characteristics. An assumption was made in the calculations that the internal lighting equipment and domestic hot water loads would remain the same for each of the three conditions examined. Table 6 compares percent savings resulting from the sound insulation and thermal modifications with the existing conditions.

Dwelling 1, built in the 1850s, has little thermal insulation. The building envelope is in fair condition and it is the largest ($2,100\ ft^2$) of the three dwellings examined. The sound insulation modifications resulted in only a 3 percent savings for the total energy costs. If this dwelling were to be modified to conform to the AIA recommended practice for thermal insulation, the yearly energy costs could be reduced more than 30 percent.

Dwelling 2 ($1,400\ ft^2$) and 3 ($1,100\ ft^2$) were built in the 1950s and the 1920s, respectively. These dwellings have slightly better thermal insulation than Dwelling 1; however, air infiltration at the window perimeter is high. The sound insulation modifications would result in 15 and 18 percent savings, respectively, for the total energy costs for these two dwellings. Upgrading the insulation at these two dwellings to the AIA recommended practice for thermal insulation would reduce the yearly energy costs by 20 and 40 percent, respectively. The total utility costs illustrated include a portion of the fixed costs for lighting, appliances, and domestic hot water, which are assumed to be the same for the existing and modified conditions.

Table 6 also presents the percent savings relative to the recommended AIA thermal insulation practice directly attributable to the sound insulation modifications. For the three dwellings studied, these savings amount to between 10 and 75 percent.

TABLE 5 UTILITY COSTS IN DOLLARS FOR THREE MODIFICATION SCHEMES

	Dwelling No. 1			Dwelling No. 2			Dwelling No. 3		
	Exist	Snd Ins	Ther	Exist	Snd Ins	Ther	Exist	Snd Ins	Ther
Total	1,927	1,873	1,284	991	848	781	982	808	591
Heating	662	641	102	448	343	157	442	320	144
Cooling	277	267	241	114	99	74	115	93	81
Fans	175	153	129	95	71	46	105	76	46

Exist = Present utility costs without modifications.

Snd Ins = Utility costs after sound insulation and HVAC modifications.

Ther = Utility costs after sound insulation and thermal modifications per AIA recommendations.

TABLE 6 PERCENT SAVINGS FROM EXISTING THERMAL CONDITIONS FOR SOUND INSULATION AND THERMAL MODIFICATIONS

	Snd Ins	Ther	Percent Ther Savings Due to Snd Ins
Dwelling No. 1	3%	30%	10%
Dwelling No. 2	15%	20%	75%
Dwelling No. 3	18%	40%	45%

Snd Ins = Utility costs after sound insulation and HVAC modifications.

Ther = Utility costs after sound insulation, HVAC, and thermal modifications per AIA recommendations.

CONCLUSIONS

Sound insulation modification designs for three different dwellings have been described. Modifications included replacing windows and doors and increasing the mass of certain walls and ceilings. This procedure resulted in a measured improvement in the dwelling's existing noise reduction by 4 to 10 dB. The HVAC system in each dwelling was modified to provide forced-air heating and cooling capabilities. The sound insulation modifications resulted in a calculated energy savings of 3 to 18 percent over the existing conditions. Increasing the thermal insulation to meet current AIA recommended practices would improve the energy savings by 20 to 40 percent. The sound insulation modifications alone provide between 10 and 75 percent of the energy savings that would result if the AIA thermal insulation practice were to be implemented in the dwellings.

REFERENCES

1. *Airport Noise Compatibility Planning.* Federal Aviation Regulations, Part 150 (14 CFR 150), FAA, U.S. Department of Transportation, Washington, D.C., 1989.
2. American Society of Heating, Refrigerating, and Air Conditioning Engineers. *ASHRAE Handbook: 1989 Fundamentals.* Atlanta, Ga., 1989, Chapter 23.
3. American Society of Heating, Refrigerating, and Air Conditioning Engineers. *ASHRAE Handbook: 1989 Fundamentals.* Atlanta, Ga., 1989, Chapters 22–28.
4. *Architect's Handbook of Energy Practice*, The American Institute of Architects, Washington, D.C., 1987.

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