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REPORT NO. 3903

ENERGY CONSERVATION AND NOISE CONTROL IN RESIDENCES

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D.N. Keast

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Prepared for:
Office of Noise Abatement and Control
United States Environmental Protection Agency
Washington, D.C.

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August 9, 1978

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Office of Noise Abatement and Control
United States Environmental Protection Agency
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Energy Conservation
and
Noise Control in Residences

SUMMARY

There are several ways for reducing the intrusion of noise into a dwelling that can also reduce the energy required to heat or cool the building. Similarly, efforts to reduce energy consumption can provide a concomitant noise-reduction benefit. This memorandum discusses and provides quantitative estimates of these synergistic benefits. In addition, suggestions are provided for resolving apparent conflicts between the independent objectives of building energy conservation and building noise control.

A graphic summary of the principal results of this study is given in Fig. S-1. All of the building features illustrated involve reducing the heat energy and the acoustic energy that flows through the building envelope. The single most important step that can be taken to achieve both energy-conservation and noise reduction in dwellings is the sealing of air leaks in the building envelope. When done for noise-control (which does not require that <u>all</u> leaks be sealed), an estimated 15% to 20% of the total annual heating/cooling energy requirement of the building can be saved. Correspondingly, if leaks are sealed for energy-conservation purposes, a 5 to 10 dB improvement in the interior noise level due to external noise sources will result.

The use of double glazing, insulated glass, or storm windows will all result in comparable energy savings; 6 to 8% of the annual heating/cooling requirement, assuming a modest window-to-wall area ratio. However, only storm windows will provide a significant noise-reduction benefit, because of the large spacing possible between the two glass barriers.

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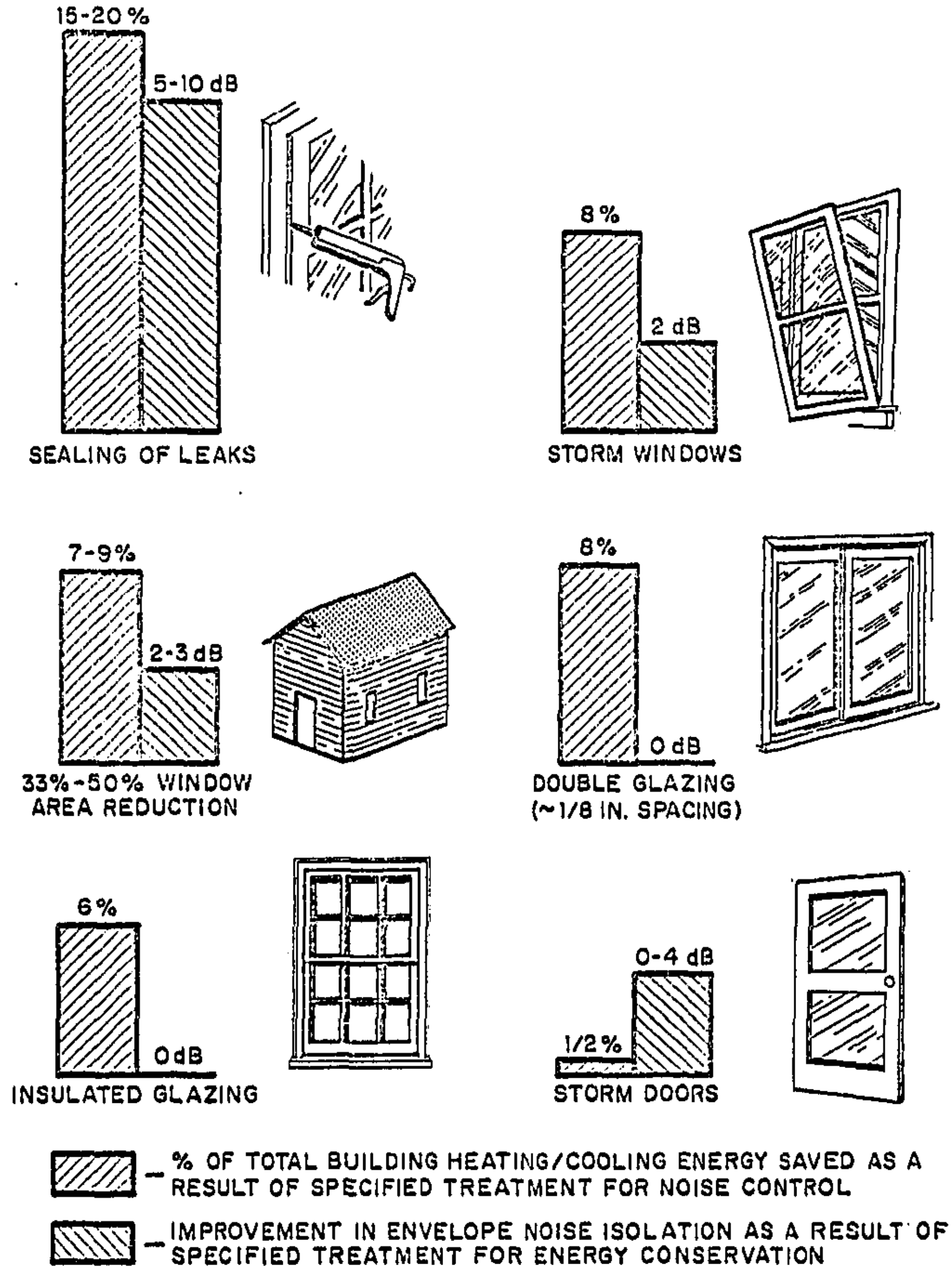

FIG. S-1 SUMMARY OF NOISE-CONTROL AND ENERGY-CONSERVATION BENEFITS RESULTING FROM SELECTED FEATURES OF RESIDENTIAL BUILDINGS.

Reducing the ratio of window to total wall area by a factor of 33 to 50% will result in both a 7-9% energy saving and 2-3 dB noise reduction. The use of storm doors (or a vestibule) produces a small (1/2%) energy saving, but as much as 4 dB of noise reduction for the room into which the door opens.

It is a common misconception that the addition of thermal-insulation to walls will improve their noise isolation properties. This is generally not true. It is also not true that landscaping around a residence will improve its outdoor noise environment. Both of these things can, however, reduce the energy consumption in a building.

Two model building codes, one prepared by EPA for the control of noise in dwellings and one prepared by DOE to minimize building energy consumption, are discussed in appendices to this report.

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Energy Conservation and Noise Control in Residences

1. Introduction

1.1 Background

Scientists and engineers have known for some time that energy conservation in buildings and the control of disturbing noise in buildings are inter-related technologies. However, the average homeowner is typically unaware of this fact. He may not appreciate that if he takes certain steps to reduce his heating/cooling bills, he can make his home quieter inside at the same time. Likewise, in attempting to make his home quieter, he can also reduce home energy consumption. The purpose of this memorandum is to describe why this is so, and to indicate ways that the combined benefits of energy conservation and noise control can be optimized.

The propagation of noise from outdoors to the inside of a house is determined by certain properties of the outside walls and roof of the building -- called here the "building envelope". Obviously, the heat loss or gain of the house relative to the out of doors is also determined by features of the building envelope. The most important property of the envelope, as far as noise-control is concerned, is the effective weight per unit surface area of the structure. See Fig. 1.1. A heavy concrete wall will transmit less noise than a light frame wall. As a natural result, an important secondary property is the size of any holes or leaks through the envelope. Because the leaks have no interfering "weight", outdoor noise can enter through them unattenuated.

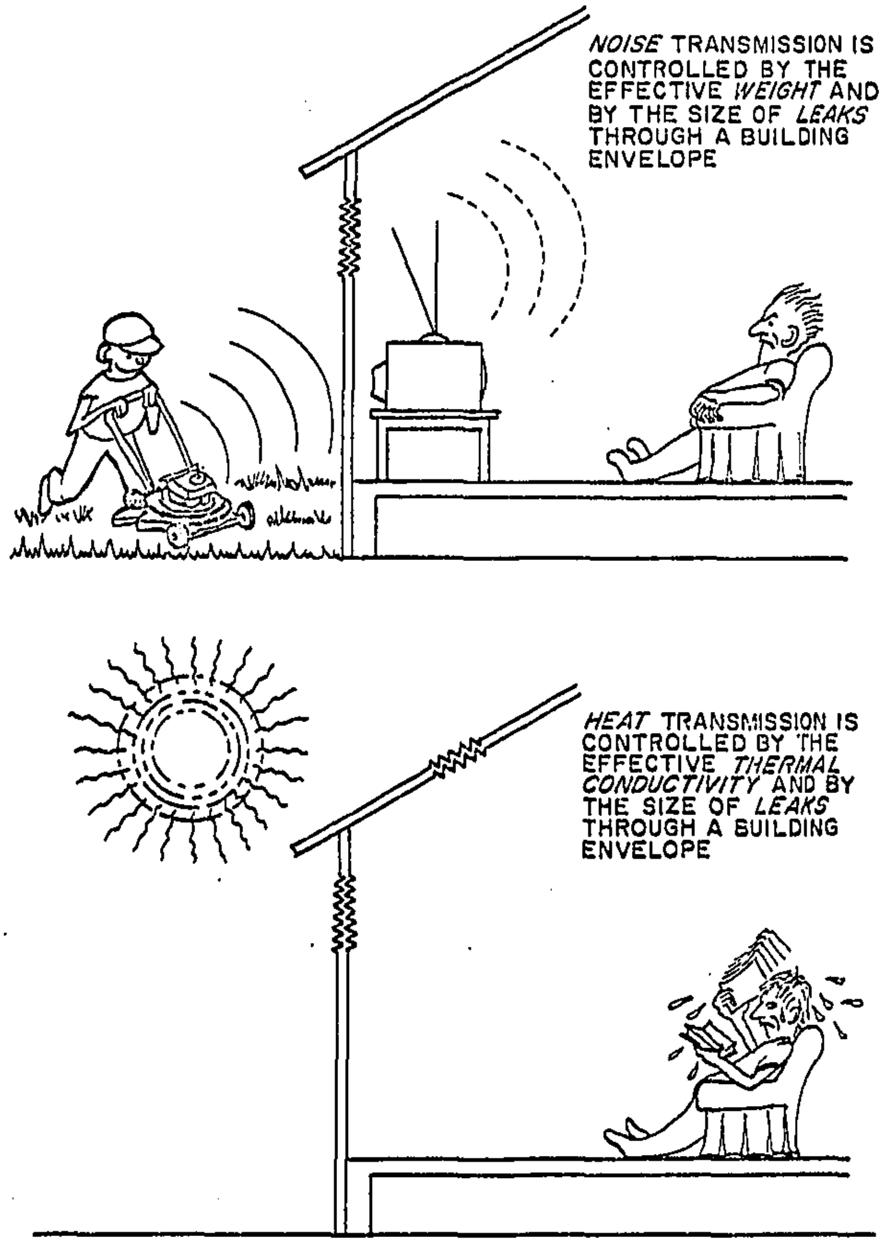


FIG. 1.1 PROPERTIES OF BUILDING ENVELOPES AFFECTING NOISE TRANSMISSION AND ENERGY CONSUMPTION.

On the other hand, the most important property as far as heat flow is concerned is the effective thermal conductivity of the envelope. This is also shown on Fig. 1.1. A wall that is insulated to have low thermal conductivity will have much less heat flow than a corresponding uninsulated wall. Again though, the size of any leaks through the envelope is of significant secondary importance. The leaks have no insulation, and permit free flow to the out of doors of the air the homeowner has paid to heat or cool.

As far as the most important envelope properties are concerned, the weight of a building structure is generally unrelated to its thermal conductivity. This would suggest that achieving adequate noise control does nothing for energy conservation, and vice versa. We will see below that this is not always true; but before addressing that paradox some important examples of the independence of weight and thermal conductivity should be pointed out. The heavy concrete wall mentioned above as having excellent noise-reducing properties is a very good conductor of heat. Thus, lacking insulation, it provides little energy-conservation benefit. Likewise, adding insulation to the cavities in a typical frame wall can greatly reduce its thermal conductivity, but contributes almost nothing to its noise-reducing properties because it adds little to the weight of the wall.

Now about that paradox. In most low-rise residential structures, the noise-reduction and thermal properties of the building envelope are controlled more by the windows and doors than by the wall and roof structure. Whereas a typical frame wall may weigh 15 lb/ft^2, single-strength window glass weighs about 1.5 lb/ft^2. Thus, ten times as much sound energy can enter through a square foot of window, compared to that through a square foot of wall. The style, treatment and relative size of the windows thus have a disportionately large effect on the noise-reducing properties of the envelope. The same is true of exterior doors, which typically weigh 3-4 lb/ft^2.

From a thermal point of view, the thermal transmittance of a typical insulated frame wall is about 0.08 BTU/hr ft^2°F whereas that of glass is 1.0 -- twelve times greater. Thus, the windows are also very significant to the thermal properties of the building envelope. (This is less true of unglazed doors. A 1 3/4 in. solid-core wood door is only four times worse than an insulated frame wall, about 0.3 BTU/hr ft^2°F.)

Now if we add the fact that cracks around doors and windows are one of the common kind of leakage paths for both air and noise, it becomes clear that such wall penetrations are very important to both the thermal and acoustic properties of a typical residential building.

This similarity of the effects of wall penetrations on thermal and noise-reduction properties of walls is illustrated on Figs. 1.2 and 1.3. In both cases, a typical frame exterior wall is assumed with wood siding, a gypsum board interior, and R-11 insulation.

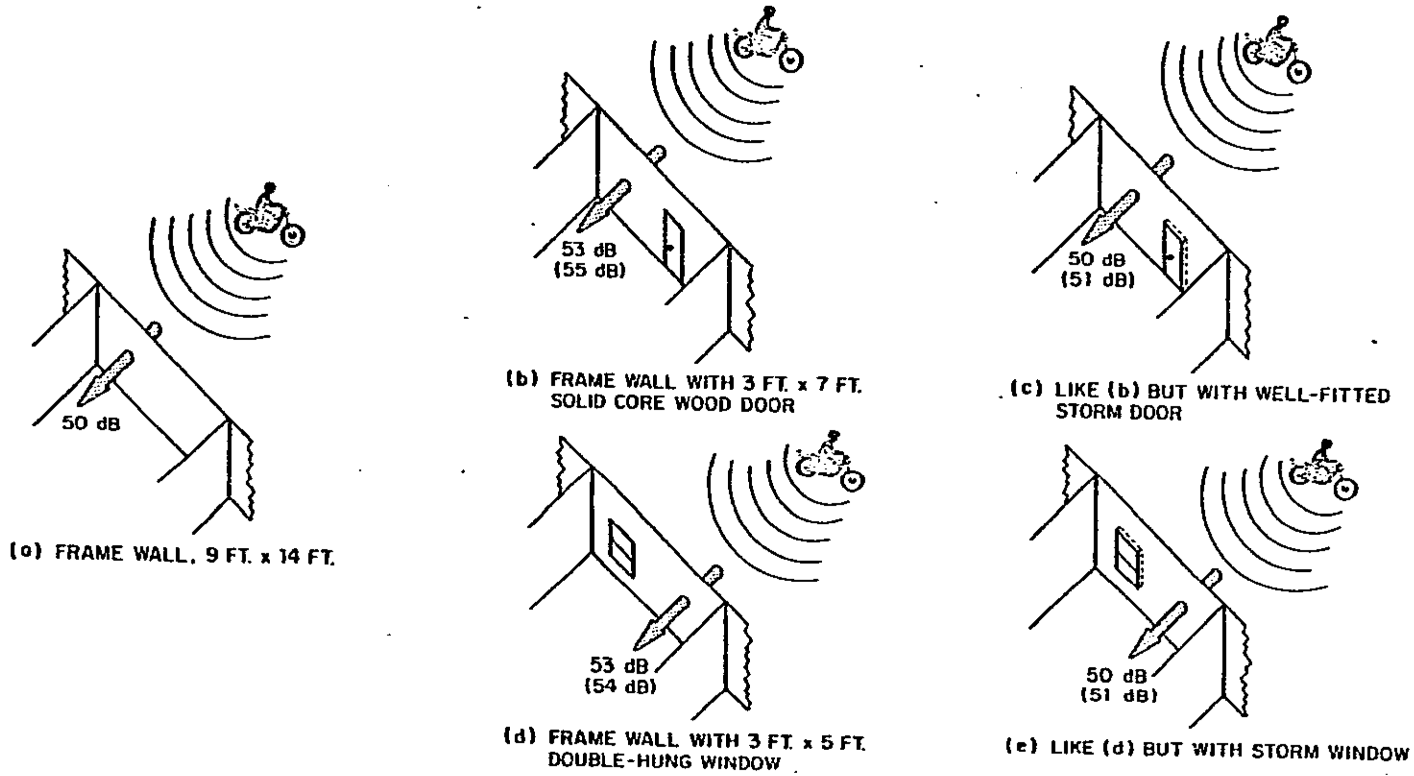
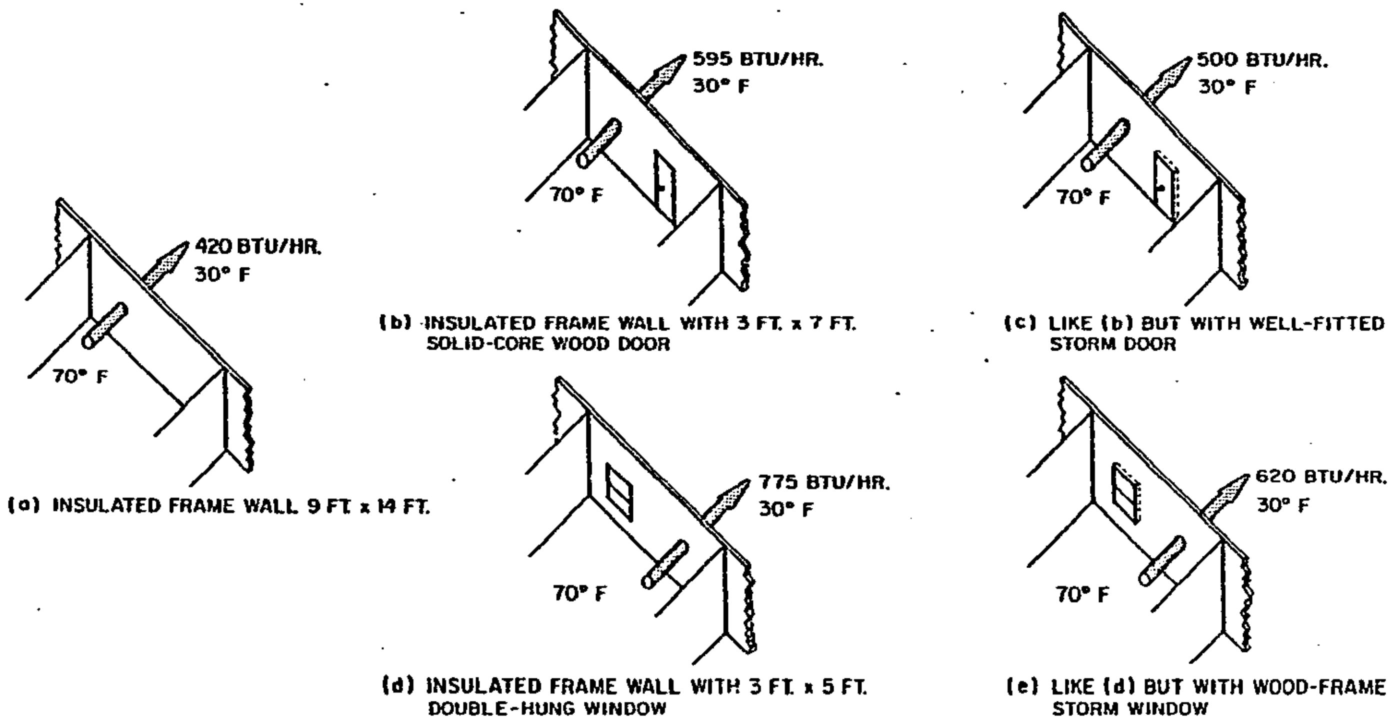


FIG. 1.2 NOISE-REDUCTION PROPERTIES OF A FRAME EXTERIOR WALL
(Numbers in parentheses include the effect of leaks around the doors and windows.)



(a) INSULATED FRAME WALL 9 FT x 14 FT.

(b) INSULATED FRAME WALL WITH 3 FT. x 7 FT. SOLID-CORE WOOD DOOR

(c) LIKE (b) BUT WITH WELL-FITTED STORM DOOR

(d) INSULATED FRAME WALL WITH 3 FT. x 5 FT. DOUBLE-HUNG WINDOW

(e) LIKE (d) BUT WITH WOOD-FRAME STORM WINDOW

FIG. 1.3 THERMAL PROPERTIES OF A FRAME EXTERIOR WALL

(Calibrations assume penetrations are not sealed, and there is an applied pressure difference across the wall.)

In Fig. 1.2, a noise source is postulated that produces a 50 dB sound level inside the wall with no penetrations, as in Fig. 1.2a. The addition of a solid-core wood door which is perfectly sealed raises the interior noise level to 53 dB (this is a doubling of sound energy). Unsealed but normally closed, the noise level would be 55 dB. See Fig. 1.2b. However, a storm door (Fig. 1.2c) essentially corrects the problem. A similar situation exists when a window is added (Fig. 1.2d), but it can be corrected with a storm window (Fig. 1.2e).

For the same wall and wall penetrations, the thermal losses with a 40°F temperature difference are shown in Fig. 1.3. The unpenetrated wall looses 420 BTU/hr (Fig. 1.3a). The addition of a solid-core door increases this 40% to 595 BTU/hr (Fig. 1.3b), but this can be partially corrected with a storm door (Fig. 1.3c). The window is even worse (Fig. 1.3d), increasing the loss by 85%. However, this can be corrected to 48% with a storm window (Fig. 1.3e).

The opportunity for synergistic benefits -- for getting both noise reduction and energy conservation for the price of one, now boils down to:

- proper treatment of windows and doors
- sealing of leaks in the building envelope

The most common method for reducing heat loss through windows, at least in colder climates, is to add storm windows. Acoustically this double barrier is also very effective -- even more so than doubling the weight of the glass. This is also true for the addition of storm doors. The sealing of air leaks has a direct benefit from both a noise-control and an energy-conservation point of view. Methods for achieving these benefits are discussed in greater detail in Section 2 of this memorandum.

1.2 Basis of Study

To a considerable extent, this memorandum is based upon a study of two model building codes. One, prepared by the United States Department of Energy, is entitled "Model Code for Energy Conservation in New Building Construction".* The other is entitled "Noise Control for Building Codes: Model Noise Control Provision and Implementation Manual". This is a June, 1978, draft of a document being prepared by the United States Environmental Protection Agency. Opportunities and methods for achieving both energy conservation and noise control in residential buildings have been extracted from these model codes for discussion in Section 2.

In some cases, however, there are inconsistencies or conflicts between the provisions of the two Model Codes -- noise control requirements that could increase energy consumption; or energy-conservation requirements that could result in noise problems. These are discussed in Section 3, with some suggestions as to how they can be avoided.

Finally, some areas of potential misunderstanding about noise-control and building energy conservation are covered in Section 4. The two Model Codes are synopsized in the Appendices.

*SAN/1230-1, Dec. 1977.

1.3 Items Not Considered

Noise problems in residences are not due solely to sounds intruding from outside. Annoying noise from adjacent spaces within the same building is a common problem, particularly within multi-family dwellings. The noise of appliances and building mechanical equipment is often an issue. Structure-borne sounds -- either in the form of impact (i.e. footfall) noise from within the building or in the form of vibration from nearby railroads or track routes can also be a problem. In general, the solution to these kinds of noise problems would have no concomitant energy-saving benefit, so they are not considered in this memorandum.

Likewise, there are many ways to save energy within a residence besides improving the building envelope. Optimizing heating/cooling system efficiencies, thermostat settings, reduced or more efficient lighting, improved appliance efficiencies and reduced hot-water consumption are all very important. However, these energy-saving actions generally have no substantial effect on the noise environment within the dwelling, so they have also not been considered here.

2. Methods to Improve Both Noise Reduction and Energy Conservation in Residential Buildings

2.1 Reducing Leaks

As far as leaks are concerned, the objectives of both the EPA and DOE model codes are the similar: reducing or controlling unnecessary air and sound leakage paths through building envelopes.

The requirements of the DOE Model Code for Energy Conservation, based as it is on ASHRAE 90-75, are not particularly stringent with regards to reducing air leakage ("infiltration") in residential buildings. Arthur D. Little Inc. (ADL) estimated that energy losses would be reduced by only 0.8% (apartments) to 1.3% (single-family homes) in residential structures if the infiltration provisions of ASHRE 90-75 were applied nationally*. Based upon this estimate, noise-control benefits would be negligible.

On the other hand, some provisions of the DOE code require "approved" caulking and weatherstripping, and the use of low-leakage windows and doors.

The envelope requirements of the EPA Code are variable, depending upon the outdoor noise level at the site. In multifamily residences, it is pointed out, it may be desirable not to minimize the intrusion of outdoor noise in order to mask out sounds coming through party walls. (See Appendix B.) However, in noisy (urban) areas the code would generally require some attention to sealing details of the building envelope.

*"An Impact Assessment of ASHRAE Standard 90-75", report to the Federal Energy Administration, Dec. 1975.

For the purpose of this discussion, we concentrate on the objectives of the two Model Codes as applied to single-family residences, to avoid the subtleties of the needs for masking noise from outdoors in multi-family buildings. We further assume that structures will be built to minimize acoustic and/or air leakage through the envelope within practical economic limits.

From a study of 50 homes in the Dallas, Texas area, Texas Power and Light (TP&L) estimated that the average home underwent 1 1/2 air changes per hour due to air leaks through the structure.* Unpublished work by BBN on a small number of homes in the Boston area indicates even higher leakage rates. For a 40°F temperature differential (70° inside, 30° outside) and an 1800 sq. ft. house, 1 1/2 air changes represents a loss of about 16000 BTU. Perhaps 2/3 of this energy could be saved by careful sealing of the building.

The typical air-leakage paths found during the Texas Power and Light Study, and their average importance in terms of their contribution to the total air leakage rate, are indicated on Fig. 2.1. The cross-hatched areas, representing 48% of the total, are not likely to be important noise-leakage paths. This is because some of them open into the attic space rather than to the out of doors. In the case of bathrooms and kitchens, it is because these are not particularly sensitive locations in residences for noise from the out of doors. The remaining 52% represent noise-leakage paths that compromise the potential noise-reducing capability of the building envelope into sensitive interior locations.

*G.E. Caffey, "Residential Air Infiltration", Texas Power & Light Company, Oct. 1977.

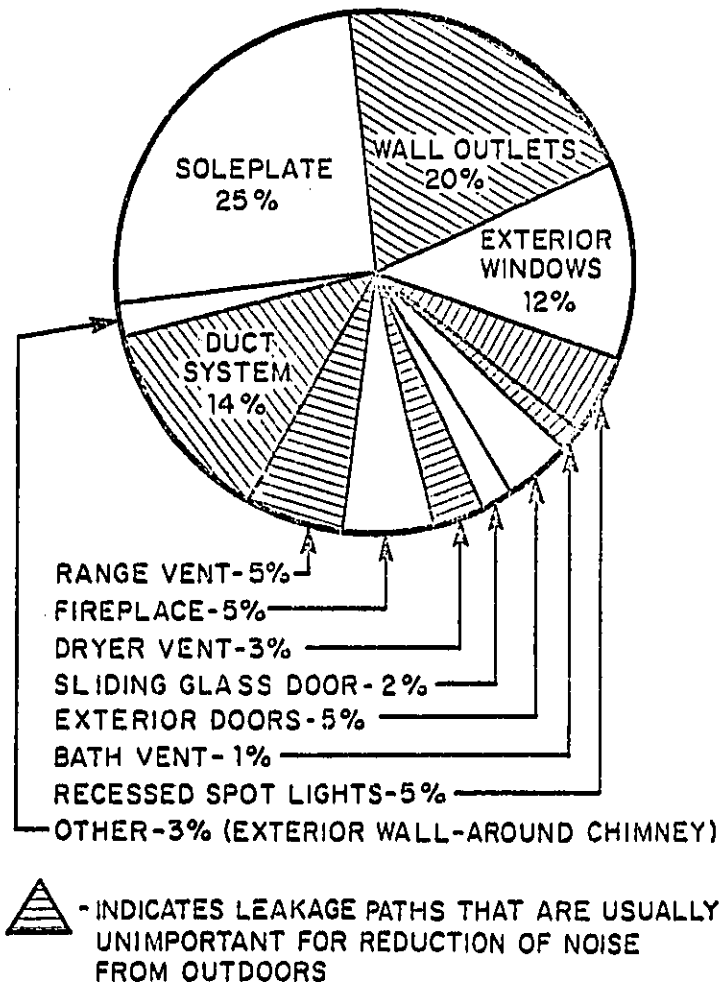


FIG. 2.1 AIR LEAKAGE TEST RESULTS FOR AVERAGE HOME OF 1,780 SQ.FT.*
(From 50 Homes Tested by Texas Power & Light Co. in the Dallas, Texas area.)

*From G.E. Caffey, "Residential Air Infiltration," Report of Texas Power & Light Co., Oct. 1977.

The magnitude of this compromise, from a noise-control point of view, will vary widely depending upon the construction and furnishing details of the particular building. An estimate can be made based in part upon a study by the National Bureau of Standards entitled "Acoustical and Thermal Performance of Exterior Residential Walls, Doors and Windows".* NBS determined the "Sound Transmission Class" (STC, a measure of the noise-reducing properties of a structure determined in accordance with ASTM E413-73) of a number of doors and windows, both in their normal configuration and with all leaks sealed. Some of their results are listed in Table I. These indicate a range of 3-10 dB in the deterioration of the acoustic performance of typical doors and windows due to sound passing through the cracks around the doors and window sashes. (The effects of leaks around door and window frames are not included). Of course, complete sealing of windows and doors is not practical, and thus the benefit of improved weatherstripping would be somewhat less than 3 to 10 dB. Actual experience in the field would be highly variable because of differences in construction practice and deterioration of weatherstripping with use.

The Implementation Manual associated with the EPA's Model Code Provision for Noise Control in Buildings recommends that laboratory STC data be reduced by 5 dB when estimating field performance of a wall. This is an allowance for acoustic "flanking paths", which are frequently air leaks as well.

The data of Fig. 2.1 indicate that window sash and door leaks represent about 40% of the acoustically significant air leaks to the out of doors from a Dallas residence (19% out of

*NBS Building Science Series Publication No. 77, Nov. 1975.

48%). This suggests that the figures in the last column of Table I could be increased by 4 dB in order to estimate the acoustic deterioration due to <u>all</u> leaks in a residence (7 to 14 dB for complete sealing). This seems high, based upon experience.

We conclude that careful sealing of air leaks through the envelopes of residential buildings would reduce inside levels of exterior noise an average of 5 dB; and as much as 10 dB compared to the more casually constructed homes. It is assumed, of course, that the windows and doors are closed.

Energy loss due to the heating/cooling of infiltrated air in single-family residences varies greatly across the country, depending upon the local climate and building practices. Numbers have been quoted ranging from 25% to 40% of the total heating/cooling energy requirement, although we are aware of no national studies that confirm this estimate. ADL, in their study of the impact of ASHRAE 90-75, estimated 19% nationwide. Hittmann Associates, in a report done for HUD, estimated 51% for single-family residences in the Baltimore area.* In a study of town houses at Twin Rivers, New Jersey, Princeton University found about one-third. Based upon this limited information, and realizing that only about half the possible leakage paths would be treated for noise-control purposes, (see Fig. 2.1), we estimate the energy savings obtainable by sealing air-leakage paths for noise-control purposes in single-family dwellings to be about 15% to 20% of the energy required to heat/cool the house.

*Residential Energy Consumption-Single Family Housing: Final Report", HUD Publication No. HUD-PDR-29-2. The document has two dates: March 1973 and September 1975.

TABLE I

Reduction in STC Due to Leakage Around
Doors and Window Sashes
(From NBS Building Science Series Publication No. 77)

Item	STC, Sealed	STC, Normally Closed & Locked	Effect of Seal
door, flush, solid core, weatherstripped	30 dB	27 dB	3 dB
double-hung window single-strength glazing	29 dB	23 dB	6 dB
door, sliding, glass wood-plastic	31 dB	26 dB	5 dB
window, aluminum sliding	28 dB	24 dB	4 dB
window, aluminum casement	31 dB	21 dB	10 dB

2.2 Window and Door Treatments

Two methods are available for reducing heat flow through windows: reducing the total window area, and altering the window to reduce its thermal conductivity. The same techniques are applicable to doors, although reducing the total door area is usually not feasible in residential structures. All of these techniques will likewise reduce the noise transmitted through the building envelope. Some of the possible effects are shown on Figs. 1.2 and 1.3.

The DOE Model Code does not explicitly address requirements for the thermal conductivity of windows and doors (beyond infiltration requirements). But it does encourage minimizing energy transfer through windows and doors by establishing overall envelope requirements. The EPA Model Code is similarly general, except that:

- The EPA Code allows for some outside noise intrusion in order to mask the sounds of neighbors' activities in multi-family dwellings.
- The EPA Code effectively requires that windows be closed and inoperable at noisy housing sites (thus requiring mechanical ventilation).

The following analysis of the potential synergistic benefits of window and door treatments for noise control or energy conservation assumes single family residences with windows and doors closed. It is further assumed that maximum practical effort is given to achieving the objective -- be it either minimum noise transmission or minimum heat transfer. In actual practice, there would be great variability due to differences in housing styles, construction practice and local climate.

It is not uncommon, at least in the Northeast, to build new energy-conserving houses with 2/3 to 1/2 of the "normal" amount of window area. This is usually combined with 6 in. exterior wall cavities containing R-19 insulation, and with other features necessary to yield significant energy savings. The concomitant increase in noise reduction through the envelope due to the reduced window area is 2-3 dB. A similar reduction in window area for noise-control purposes would save 7% to 9% of the heating/cooling energy requirements for the building, as estimated from Chart 6-A of the DOE Model Code (assuming 30% of the envelope losses are through the walls).

Window modifications to reduce energy loss include double glazing, the addition of storm windows, and the use of "insulating" glass. The thermal benefits of these modifications are approximately as indicated in Table III, from the ASHRAE Handbook of Fundamentals. Also indicated on Table III, from the NBS study, are the noise-reduction benefits attributable to the same window modifications. Note that storm windows are far more effective acoustically than double glazing, primarily because of the greater spacing possible between the primary sash and the second window. Although not indicated on Table III, storm windows can also be thermally more effective than double glazing on operable windows, to the extent that they reduce infiltration. The author estimates the additional thermal benefit due to reduced infiltration through storm windows to be 15%. Unfortunately, storm windows are essentially unavailable in many parts of the country, and are sometimes considered functionally distasteful.

TABLE III

Benefits of Window Modifications - Windows Sealed
(from the ASHRAE "Handbook of Fundamentals")

	Basic Window Single-Glazed	Insulating Glass, 7/16"	Double Glazing (1/8" Spacing)	Storm Window >2" Spacing
Thermal Transmittance BTU/hr ft^2°F	1	0.66	0.5	0.5
% Thermal Improvement	-	33%	50%	50%
STC, dB	28	29	29	34
Noise-reduction Benefit, dB	-	1	1	6

The percentage whole-house benefits of the window modifications in Table III will be less than the benefits due to the modification alone, of course, because windows do not constitute the entire building envelope. In general, the whole-house benefits will vary in proportion to the percentage of window area in the envelope. If we again assume 30% of the envelope thermal losses are through the walls, and also assume a 15% window area-to-wall area ratio, Charts 6-A and 6-B of the DOE Model Code indicate an 8% saving due to double glazing. Adjusting for the difference in thermal transmittance indicates a corresponding 6% saving with insulating glass.

The noise-reduction benefits of double glazing (with $\sim$ 1/8 in. spacing) and of insulating glass are negligible for small window-to-wall area ratios. On the other hand, tests reported by Driscoll* for 14 houses in Upstate New York indicate an average 2 dB(A) benefit due to storm windows, for highway noise.

The thermal and acoustical effects of door modifications are similar to, but less significant than those of window modifications. Two door treatments are generally available: the use of storm doors and the use of vestibules. Storm doors can provide about a 50% decrease in the heat transferred through the door opening, and about a 7 dB improvement in the STC. The thermal benefit of a vestibule is about the same, although the acoustical benefit is greater because of the increased spacing between the primary and storm doors. In most new residences, however, vestibules are not considered economically practical.

*D.A. Driscoll, J.P. Dulin, Jr. & D.N. Keast, "Attenuation of Northern Dwellings to a Linear Source of Noise," J. Acoust. Soc. Amer. (A) 63 Supp. 1, 1978.

The whole-house benefit of door modifications is much less than the above figures because doors make up such a small percentage of the total building envelope area. From a noise-control point of view, the improvement due to the addition of a storm door will typically be about 4 dB in the room into which the door opens (Fig. 1.2), and neglegible elsewhere in the home. The overall energy saving, from the Hittman report, will be about 1/2 of 1 percent.

2.3 Other Areas of Possible Benefit

There are other areas of overlap where efforts to reduce interior noise levels could result in energy savings, and vice-versa. Most of these are of minor importance in typical residences, and all are so variable from building to building that they are impossible to quantify.

The use of hung acoustical-tile ceilings, as in kitchens and basement game rooms, will somewhat reduce interior noise levels (including levels due to outdoor sources). It will also result in some energy savings in those cases where the treated ceiling forms a portion of the building envelope. Likewise, the use of heavy drapes to block windows will have both thermal and acoustical benefit.

Massive walls, including massive interior partitions, are sometimes used to provide passive heat storage, often with a diurnal time constant, in hot climates. Such walls could provide large noise isolation if their acoustic properties are not compromised by windows and other penetrations. They can be particularly effective between dwelling units in multi-family buildings.

The DOE Model Code encourages the insulation of ductwork for conditioned air; and of steam, hot-water and chilled-water piping. Such thermal insulation can have some additional benefit in reducing mechanical-equipment noise in buildings. To the extent that fiberous-glass ducts are used instead of conventional sheet-metal ductwork, the noise-reduction benefit can be quite large.

3. Potential Conflicts Between Energy-Conservation and Noise-Control Objectives in Residential Buildings: Methods for Minimizing the Effects of Such Conflicts

3.1 Building Mechanical Equipment

The DOE Model Code sets lower limits to the permissible efficiencies of various items of building mechanical equipment. Suitable building noise control often requires duct mufflers, valve-noise silencers, etc. that tend to reduce system efficiencies by introducing additional pressure drops in duct-work and piping. It is, of course, quite possible to meet the efficiency requirements of the DOE Code with the necessary noise control installed -- it is just less expensive to do without it.

This potential conflict can be resolved if designers, working to the DOE Code, are urged to comply as well with the noise-control requirements of the ASHRAE Guide.

3.2 Ventilation

There are a number of differences between the DOE and EPA Model Code in their approach towards ventilation. To minimize energy consumption, the DOE Code encourages minimum acceptable mechanical ventilation, maximum use of outside air for air-conditioning when temperature conditions permit (i.e. operable windows), and automatic set-back and shut-off controls for HVAC systems during periods of low building usage. The EPA Model Code, on the other hand, endorses the use of a steadily-operating HVAC system in multi-family buildings in order to provide masking noise for privacy. Furthermore, it essentially requires permanently-closed windows and mechanical ventilation in noisy (urban) areas. Thus the DOE requirements could lead to intermitantly inadequate masking noise levels, and to excessive outside noise intrusions if windows are opened for ventilation. The EPA requirements could lead to excessive energy consumption.

A first step towards the solution to these inconsistencies, as in Sect. 3.1, is to design HVAC systems for the proper masking-noise levels in multi-family buildings. An artificial source of electronically-produced masking noise, such as is commonly used in open-plan office buildings, may be necessary where HVAC systems are designed to cycle on and off. The second step is to introduce and encourage the use in urban areas of operable windows that also provide some reduction of intruding street noise. Such windows have been used in Europe, but are not available at present in the United States.

3.3 More About Masking Noise in Multi-Family Dwellings

Most of the preceding discussion has been directed, as far as noise control is concerned, at obtaining increased noise isolation through building envelopes. This increase may occur as a natural result of building design features intended to minimize energy losses. On the other hand, we have alluded several times to the fact that a certain minimum interior noise level is essential in multi-family buildings to preserve acoustic privacy between dwelling units. If for thermal reasons the building envelope has such large noise isolation that the interior is too quiet, the building will be less habitable from an acoustic point of view.

The solution is to add a controlled interior noise level, either through careful design of the HVAC system or by electronic means.

4. Areas of Common Misunderstanding

4.1 Lack of Acoustic Benefits of Wall/Ceiling Insulation

It is a common misconception -- encouraged by misleading advertisements for insulation -- that adding thermal insulation to the walls and ceilings of buildings will improve their noise-isolation properties. As pointed out in Sect. 1, this is generally not true. It is difficult to observe outside the laboratory any difference between the acoustic properties of insulated and uninsulated frame walls commonly used in housing construction. This is amply illustrated by the data in the NBS Report mentioned previously, and the physical explanation is clear: insulation adds very little to the weight of a wall.

Now, there is an exception to this general rule. In those cases where the wall consists of two barriers that are more-or-less structurally isolated, the addition of insulation between the barriers can greatly improve the acoustic isolation of the wall. Such double walls are usually built for noise-control purposes, but are occasionally used to enclose plumbing and duct runs in residential structures. They can be built as two separate stud walls; with studs that are ripped lengthwise over most of their length; or with resiliantly-mounted plaster or gypsum-board facings.

Double-wall construction, by any of the above methods, is very rare in single-family residences. It is coming into use in multi-family buildings, but principally for party walls between dwelling units.

4.2 Lack of Acoustic Benefit Due to Exterior Landscaping

Properly designed exterior landscaping around a building can reduce the energy consumption within the building. Shading reduces the summer cooling load due to insolation, and shelter from the wind reduces heat transfer all year around. However, contrary to popular opinion, a moderate amount of foliage has no effect on outside noise levels around a building. Only a considerable quantity (i.e. propagation distances greater than 100 ft.) of dense foliage between a noise source and a residence can be expected to have any observable noise-attenuating effect.

APPENDIX A

Synopsis of Noise-Control Benefits and Disbenefits of DOE Document SAN/1230-1, "Model Code for Energy Conservation in New Building Construction" and Related ASHRAE Standard 90-75, "Energy Conservation in New-Building Design"

The DOE Model Code represents a codification, for the benefit of building-code officials, of the technical requirements of Standard 90-75 prepared by The American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE). The model code was prepared by a consortium of professional organizations concerned with building code enforcement, and is in a format most suitable to their needs. In preparing the model code, the recommendations of ASHRAE Standard 90-75 were not changed in any substantial way.

The DOE Model Code (and ASHRAE Standard 90-75) does not in general impose stringent new requirements on building practice. With respect to thermal transmittance through building envelopes, the Code simply proscribes what has been good design practice for many years. These transmittance requirements vary, of course, with the local climate. However, the Code does set minima on the thermodynamic efficiencies of building heating, ventilating and air conditioning (HVAC) equipment; and proscribes certain water-heating, lighting and temperature-control standards.

For many years, ASHRAE Standards and practices have included a consideration for acoustic noise control. This consideration has primarily been directed towards controlling the exposure of building occupants to ventilation and other building-mechanical-equipment noise, rather than to limiting the intrusion of noise from the out-of-doors. Noise-control is not mentioned in the Model Code, although the usual ASHRAE guidelines for handling mechanical-equipment noise are incorporated by reference.

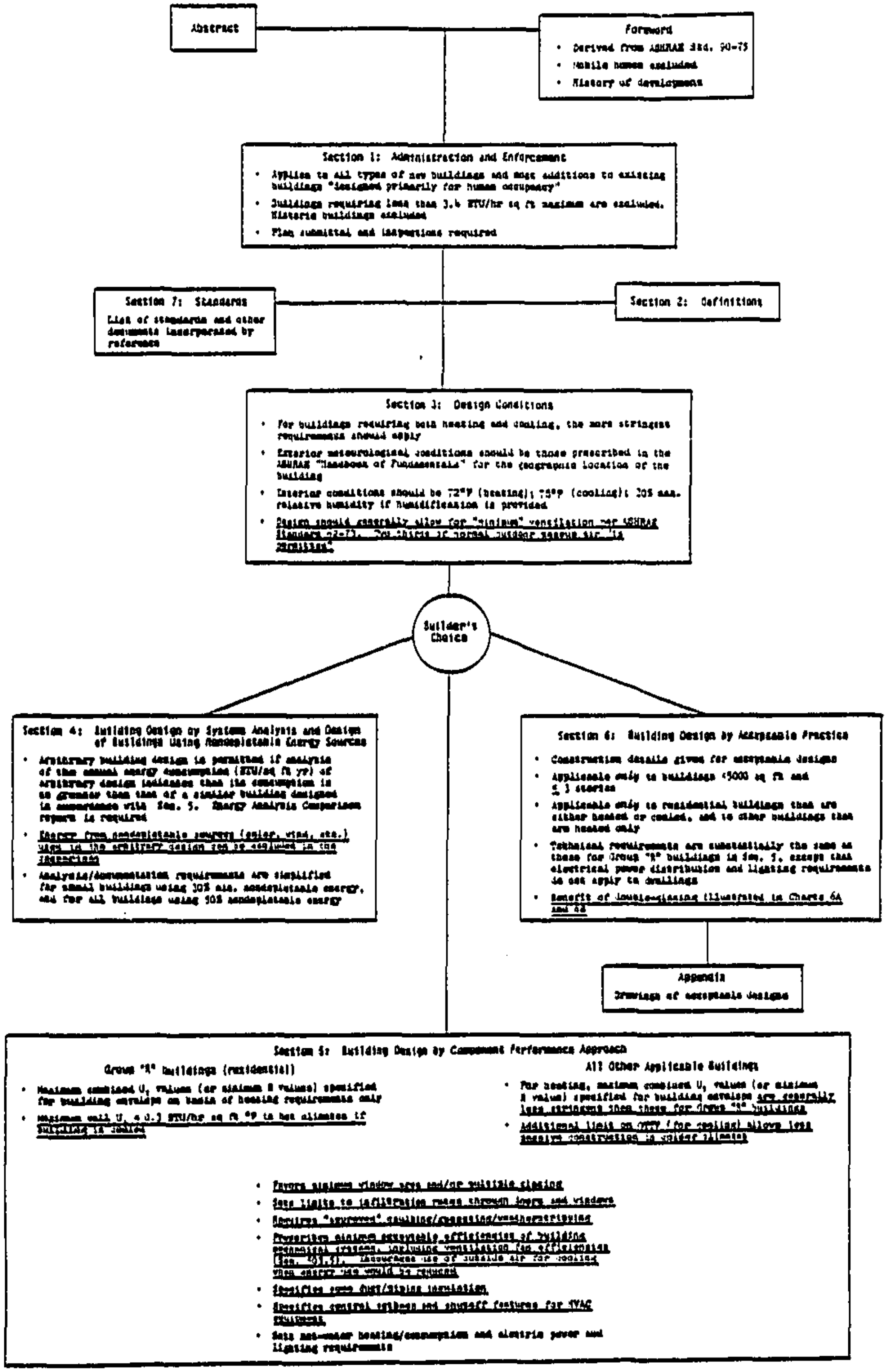
Noise due to mechanical ventilation, where installed, is a very important consideration in determining building acceptability. If this noise level is too high, it can mask speech, interfere with relaxation, and be a cause for annoyance. If the ventilation noise is too low, outside noises are not masked and will seem more intrusive, and acoustic privacy between dwelling units suffers in multi-family dwellings. Some people are particularly annoyed and claim their sleep is disturbed if the ventilation system cycles on and off so that the noise comes and goes.

The DOE Model Code is synopsized graphically on Table A-1. Highlighted on this illustration are those provisions of the code that could have building noise-control implications. Each of these is discussed in the Code description below.

The Abstract, Forward and Section 1 of the Code are generally non-technical in nature, and provide background and administrative material. Likewise, Section 2, "Definitions" and Section 7 "Standards" provide additional supporting information. Section 3 specifies the design conditions for which the proposed building is to be analyzed: exterior temperatures and winds in accordance with the usual ASHRAE practice; and interior temperatures and humidities.

The one feature of Section 3 that has building noise-control implications is subsection 303.1, which specifies that "minimum"

TABLE A.1. GRAPHIC SYNOPSIS OF "MODEL CODE FOR ENERGY CONSERVATION IN NEW BUILDING CONSTRUCTION" (DOE DOCUMENT ...) WITH EMPHASIS ON FEATURES PERTINENT TO BUILDING NOISE CONTROL.



(per ASHRAE Standard 62-73: "Standards for Natural and Mechanical Ventilation") ventilation be provided. This would tend to minimize interior noise levels in mechanically-ventilated buildings. From a noise-control point of view, this could have either a positive or a negative effect, depending upon the absolute level of the noise and the need for acoustic masking.

The builder making application under the Code has three different choices available to him to determine that his building complies with the Code. Apparently these choices are provided to accommodate the wide range of building styles and design sophistications that must be accommodated. The most direct of these approaches is that of Section 5, which requires a conventional analysis of the thermal properties of the building envelope, and of the performance efficiencies of the building mechanical systems. Section 5 is discussed in greater detail below.

The intent of the other two design choices, those of Sections 4 and 6, is to assure energy-conservation performance equivalent to that achieved by the approach of Section 5. Section 4 specifies the approach that would probably be used by the builders of larger, more complicated buildings, or by builders of unusual or unconventional structures. Using a simulation model of the proposed building (a number of computer programs are available for this purpose), the applicant must demonstrate that the total annual energy consumption of his design is no greater than that of an equivalent "standard design" building complying with the provisions of Section 5.

An interesting feature of Section 4 is that energy from non-depletable sources (solar, wind, geothermal, etc.) is not included in the energy "bill" charged to the design. If the use of energy from non-depletable sources is large, the analysis requirements are reduced as well. This will tend to encourage the use of energy from non-depletable sources. From a noise-control point-of-view, however, it may have negative implications:

- greater risk of mechanical equipment noise problems due to the additional mechanical equipment generally required to use energy from such sources.
- greater glass areas for passive solar heating, thus allowing more intrusion of exterior noise than through most opaque wall structures.
- exterior noise (of unknown magnitude) due to wind-driven electric generators.

The design approach of Section 6 is available for builders of small buildings such as single-family residences (less than 5000 sq. ft. and no more than 3 stories). It is the simplest approach of all, requiring only that the builder use one of the standard design drawings included in the Appendix of the Code, with an amount of insulation appropriate to the climate. An interesting feature of Section 6 is a pair of illustrations, Charts 6-A and 6-B, indicating the thermal benefit of double glazing. This inducement could provide noise-control benefits by reducing the penetration of outside noise into buildings.

Section 5, covering the conventional design approach, has two sets of envelope performance requirements; one for residential buildings less than three stories in height, (called Group "R" buildings) and one for all other buildings. From a noise-control point of view, overall thermal transmittance requirements are of interest primarily because they determine the maximum ratio of window to total wall area of a building. Because outdoor noise intrusions usually propagate better through windows than through walls, greater window area often means greater outdoor noise intrusion. In general, the thermal transmittance requirements of the Code are somewhat more stringent for residential buildings, except in warm climates; and are based almost entirely on heating considerations. For other, non-residential buildings, the thermal transmittance requirements are less than or equal to those for Group R buildings, but may be determined by cooling loads rather than by heating loads if air conditioning is to be installed.

For both classes of buildings, the thermal transmittance requirements are not particularly stringent, especially for walls. In southern Florida, for example (where there are less than 500 heating degree days), the limit on thermal transmittance of residential walls is 0.3 BTU/hr ft^2°F, or about R=3, if air conditioning is installed. From a noise-control point of view, this could permit large single-glazed glass areas, with a correspondingly high interior level of outdoor noise. Likewise, the minimal requirements for buildings over three stories could lead to greater use of glass in high-rise urban apartments than in rural single-family residences, thus accentuating the already serious urban noise-intrusion problem.

A final curious feature of the Code, from a noise-control point of view, is the computation of Overall Thermal Transfer Value (OTTV) for air conditioned non-residential buildings, and for buildings over three stories in height. The OTTV is partially determined by the mass of the wall structure, presumably because the specific heats of building materials (pertinent to the solar heat loading of the building) are roughly correlated with their masses. The Code can be interpreted to require more massive walls, and thus quieter interiors, in hot climates than in cold climates.

Of course, these are all unintended acoustic anomalies of the Code, the overall impact of which will be to produce a net noise-control benefit by effectively setting a limit to single-glazed glass area; by encouraging double-glazing; and by encouraging massive wall structures where appropriate.

Perhaps the most significant noise-control benefit of all, at least for residential buildings, results from Section 502.4 of the Code which restricts air infiltration. Approved caulking and weatherstripping are required on all buildings, and maximum air-leakage rates through doors and windows are established. This will reduce the principal acoustic flanking path that usually exists through the exterior walls of residential structures. The result will generally be less indoor intrusion of outdoor noise.

Section 5 of the Code also establishes a number of efficiency minima for building HVAC equipment: furnaces, air conditioners, heat pumps, etc. For example, ventilation fans must consume no more than 1/4 the energy they can remove, in the form of heated air, from a building (excluding losses through heat-recovery devices). These kinds of requirements could encourage the elimination of duct mufflers and other noise-control treatments in HVAC systems, because such treatments increase system losses. The result would be an increase in fan and air-flow noise inside mechanically ventilated buildings. An alternative to satisfying the Code: larger ducts with reduced flow velocities through the mufflers, can be quite costly.

The use of outside air for building cooling, when suitable temperature differentials exist, is encouraged by the Code. However, if this is obtained in urban settings through the installation of openable windows, the resulting interior noise levels due to outside traffic noise can sometimes be so high as to render office space unusable.

Finally the Code requires thermal insulation of duct work and piping in some installations. To the extent that this encourages the use of fiberous glass ducts, there could be a noise-control benefit relative to the use of sheet-metal ducts because of the greater acoustic attenuation of fan noise provided by fiberous glass ducts.

Provisions of the Code that limit the energy required for hot-water and lighting are not expected to have any building noise-control implications.

APPENDIX B

Synopsis of Energy-Conservation Benefits and Disbenefits of EPA Document, "Noise Control for Building Codes: Model Noise Control Provisions", June 1978

The EPA Model Code, reviewed in draft form, provides building officials with a means for controlling the noise exposure of building occupants in accordance with the EPA's published noise exposure goals.* The Code is directed primarily at residential and educational buildings, but could presumably be applied to other buildings (churches, hospitals, etc.) where noise is a consideration. It is not applicable to commercial or industrial buildings.

The Code is written in a form that allows it to be used as a replacement for Ch. 35 ("Sound Transmission Control") in the Uniform Building Code (UBC).

The Model Noise Code addresses four kinds of noise. (See Fig. B-1):

- noise from outside that penetrates the building envelope
- noise from building mechanical equipment and built-in appliances
- impact noise (in mult-family dwellings only)
- noise from neighboring apartments and public spaces in multi-family buildings

Emphasis is placed upon the fourth category, noise from neighboring spaces in multi-family buildings, because of the serious problems that have been encountered due to this type of noise in some newer apartment buildings. Because the thermal properties

*See EPA document 550/9-74-004, "Information on Levels of Environmental Noise Requisite to Project the Public Health and Welfare with an Adequate Margin of Safety". March 1974.

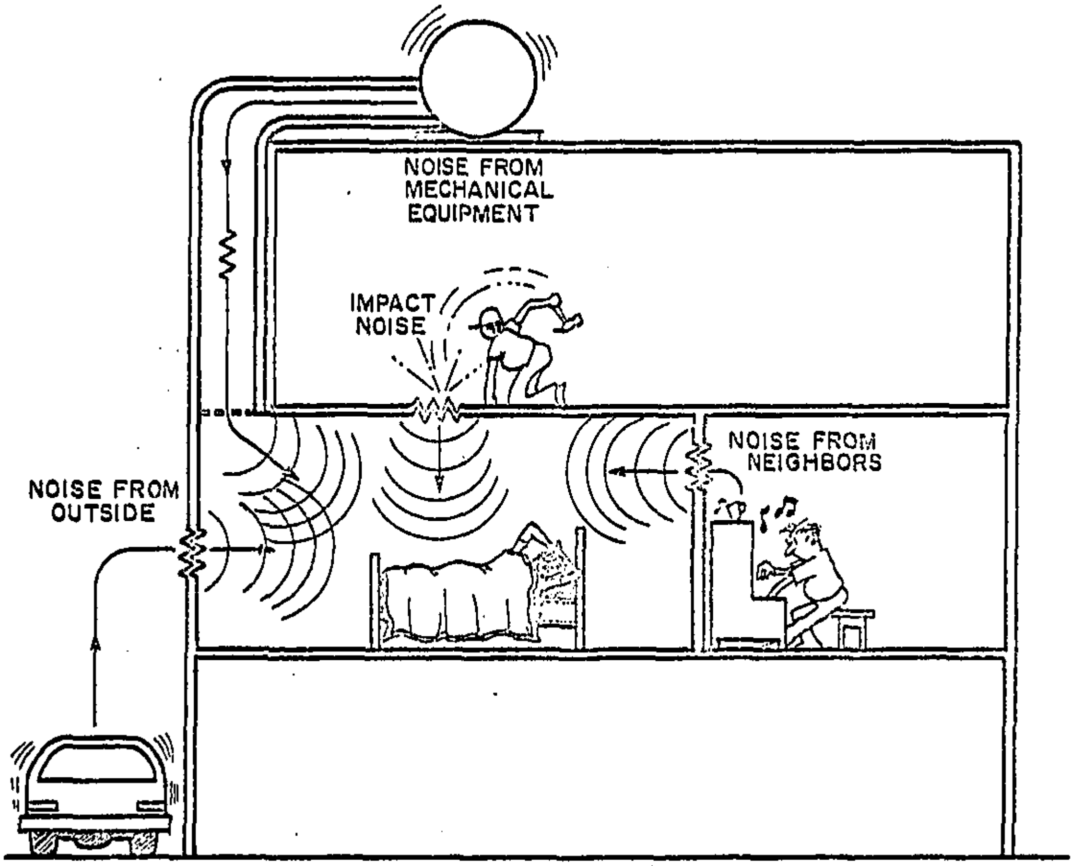


FIG. B.1. FOUR KINDS OF NOISE TO BE CONTROLLED IN MULTIFAMILY DWELLINGS.

of interior partitions are generally unimportant to building energy losses, this emphasis in the EPA Code has little bearing on building energy conservation.

The EPA Model Code is synopsized graphically on Table B-1. Highlighted in this illustration are those provisions of the Code that could have energy-conservation implications. Each of these is discussed in the Code description below.

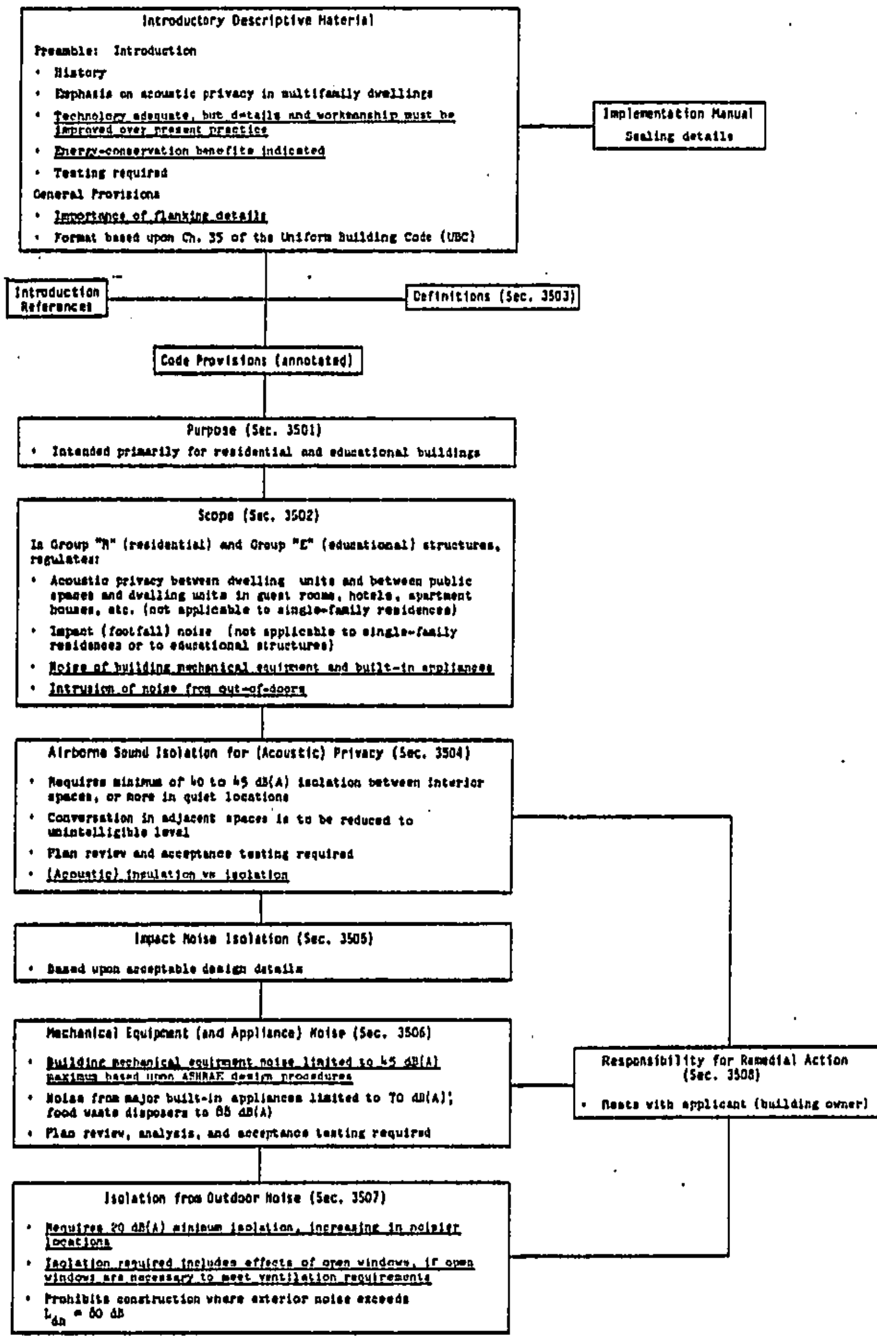
The Introduction includes a preamble and a general discussion of the Code provisions. Included is the statement that building technology is quite adequate to provide the necessary noise control, but that construction details and workmanship practices must be altered to achieve the desired performance. The problems are quite analagous to those of minimizing building energy consumption. Small holes through an otherwise adequate wall permit "acoustic flanking" which seriously compromise acoustic performance. The same holes permit air infiltration which raises energy consumption. To carry the analogy further, sloppy installation of thermal insulation frequently compromises the thermal performance of otherwise adequate walls.

The introduction digresses a bit to indicate that adequate noise-control treatment of the building exterior walls could result in energy savings, thus indicating a concomitant benefit to adaption of the Code.

Bound with the Code is an "Implementation Manual" that would aid a municipality in adopting and enforcing the Code. Of particular interest in this Manual are some drawing details from the

TABLE B.1 GRAPHIC SYNOPSIS OF EPA'S "NOISE CONTROL FOR BUILDING CODES: MODEL NOISE CONTROL PROVISIONS" (DRAFT OF JUNE 1978)

With emphasis on provisions pertinent to building energy conservation



Sound Transmission Control section of the Building Code of the City of San Diego. The details illustrate the sealing of wall penetrations (plumbing, light fixtures, electrical outlets) to prevent acoustic flanking. Such sealing would also, of course, reduce air infiltration when applied to the building envelope.

The actual Code Provisions are thoroughly annotated, and include an Introduction, References and Definitions. The Purpose (Sect. 3501) indicates that the Code is restricted to residential and educational buildings; and the Scope (Sect. 3502) indicates that four types of noise are to be controlled: between interior spaces for acoustic privacy, impact, mechanical equipment, and intrusion from out of doors (see above). Only the last two have any significant bearing on building energy utilization.

The sections devoted to Airborne Sound Isolation for Acoustic Privacy (3504) and Impact Noise Isolation (3505) thus would not generally have any effect on building energy consumption. However, an interesting technical sidelight is provided by the commentary in Sect. 3504(b) on acoustic "insulation" vs. acoustic "isolation". The acoustic insulation of a wall element (which is unrelated to thermal insulation) is a property determined for that single wall element under controlled laboratory conditions. Acoustic isolation, on the other hand, is a measure of acoustic performance that can actually be achieved in a building when the wall is installed with associated utilities, penetrations, etc. This is usually less than the laboratory performance, and the difference is computed by determining the sum of the contributions of parallel sound paths through and around the wall. The computation is directly analagous to that of Fig. 1, pp 26, of the DOE Model Code for Energy Conservation. See Appendix A.

Section 3506 establishes limits for interior noise from building mechanical equipment and built-in appliances. ASHRAE noise-control design techniques are incorporated by reference.* The performance requirement of 45 dB(A) for building mechanical equipment (roughly equal to NC-40 in ASHRAE terminology) is not particularly difficult to achieve. However, to the extent that achieving it would introduce losses in the ventilation system due to pressue drops through duct mufflers, this noise-control requirement would result in increased building energy consumption.

Section 3507 of the Model Code covering isolation from outdoor noise is the section having the most bearing on building energy consumption, because it affects the building envelope. The Code requires a minimum of 20 dB(A) noise isolation outdoors-to-indoors, with a greater requirement in noisier locations. This amount of isolation can be achieved by almost any typical building wall structure, so it is likely that transmission through wall penetrations like doors, windows and cracks will determine whether or not the requirement can be met. The effect will be to minimize window size and the effects of flanking (sound and air infiltration) paths, thus resulting in some energy conservation benefit.

It is interesting to note that the envelope noise isolation requirements are more stringent in noisy (i.e. urban) locations than in quiet (rural) ones. This could have the unintended effect of making urban buildings more energy-conserving than rural ones; a curious twist similar to those in the DOE "Model Code for Energy Conservation" that could result in southern buildings having a different interior noise environment than northern ones. (See Appendix A)

*Ch. 6 of <u>ASHRAE Handbook of Fundamentals</u> and Ch. 35 of <u>ASHRAE Handbook and Product Directory</u> are indicated.

The envelope isolation requirements of Sect. 3507 include the effects of open windows, if open windows are necessary to provide adequate ventilation. It is generally not possible to meet the noise isolation requirements with conventional U.S. windows when open. Thus, most builders would use sealed, inoperative windows and install mechanical ventilation in order to satisfy the Noise Code. This would significantly increase building energy consumption, and is in direct conflict with several provisions of the DOE "Model Code for Energy Conservation".

Several sections of the EPA Model Noise Code require performance testing of the finished building prior to the granting of an occupancy permit. A concluding Section of the Code, 3508, addresses the responsibilities of the building owner with respect to buildings that fail the tests.