Custom Residential Noise Insulation: Beyond the Standard

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The interior noise exposure level within the state of California for new residential dwellings is 45 dBA community noise equivalent level (CNEL). Achieving this standard can be a challenge at locations of high ambient conditions where the home would be exposed to noise from a busy freeway and an active freight and passenger railroad line. In addition, select clients or specific uses may require interior noise levels well below the state standard. The goal of this custom home design project was to exceed the state standard by as much as 10 dBA. Achieving this ambitious goal required more than the typical mitigation strategies. An exterior-to-interior noise analysis was conducted to determine the necessary architectural and acoustical requirements to achieve interior noise levels of 45 dBA, 40 dBA, and 35 dBA CNEL within five rooms of this home. In each case, sound transmission calculations were conducted that resulted in reduction ratings required by the windows, doors, roof and wall assemblies to meet the desired interior levels. Specific building elements were then developed to meet the noise ratings and ultimately the desired interior noise levels.

An analysis was conducted of the outdoor-to-indoor noise insulation characteristics of the dwelling rooms within the proposed custom single-family home to be located near the City of Santa Barbara, CA. The purpose of the analysis was to determine if the proposed single-family home would meet the City of Santa Barbara noise standards as well as the state of California Noise Insulation Standards for residential developments. The California standards[1] are found within Title 24 of the State Building Standards Code, which states the following:

Interior noise levels attributable to exterior sources shall not exceed 45 dB in any habitable room. The noise metric shall be either the day-night average sound level (L_{dn}) or the community noise equivalent level (CNEL), consistent with the noise element of the local general plan.

The CNEL is a 24-hour time-weighted noise exposure level metric used exclusively in California. The CNEL metric is calculated by adding a 5 dBA weighting for noises occurring during the evening hours (7 p.m. to 10 p.m.) and by adding a 10 dBA weighting for noises occurring during the nighttime hours (10 p.m. to 7 a.m.). These time periods and weightings were selected to reflect a person's increased sensitivity to noises during late night and early morning hours.

The proposed residential structure would be located approximately 180 feet from the U.S. Route 101 freeway, and approximately 65 feet from a Union Pacific Railroad mainline. As a result, the project site would be exposed to noise from vehicles traveling on the Rt. 101 freeway and noise from heavy freight operations.

The projected noise exposure levels due to the roadway and railroad traffic were calculated using the Federal Highway Administration (FHWA) traffic noise model[2] and the Wyle Laboratories train noise model[3], respectively. The total projected exterior noise exposure level at the nearest building face was estimated to be approximately 76 dBA. The level of outdoor-to-indoor noise reduction necessary to meet the applicable interior noise standard of 45 dB CNEL is 31 dBA. The purpose of this analysis was to determine the building upgrades necessary to achieve an interior noise levels of 45 dB CNEL, 40 dB CNEL, and 35 dB CNEL. This analysis also allows for the homeowner to determine the level of quiet designed into the house and provides the ability to determine the cost to achieve that desired level of quiet.

Methodology

The outdoor-to-indoor noise reduction for each of the rooms within the house are determined by calculating the noise reduction values of each building element that separates the interior of the room from the exterior. These building elements include windows, exterior doors, walls, and the roof-ceiling assembly. The area of each of these individual elements was calculated from the architectural plans, and transmission loss ratings were determined based on the descriptions of each element as provided in the architectural detail sheets. The transmittance of each individual element was calculated using the following:

$$\tau_i S_i = S_i * 10^{-\left(\frac{TL}{10}\right)} \tag{1}$$

where τ_i is the transmission coefficient of the *i*th element; S_i is the surface area of the *i*th element; and *TL* is the transmission loss of the element. Total noise reduction of the composite wall structure was determined by combining the noise reduction values for each of the individual components that make up the building shell using the following:

$$NR = 10\log_{10}\left(\frac{\Sigma S_i}{\Sigma \tau_i S_i}\right) - 10\log_{10}\left(\frac{S}{A}\right) - 6 \tag{2}$$

where *NR* is the noise reduction rating of the entire assembly; S_i is the surface area of the *i*th element; τ_i is the transmission coefficient of the *i*th element; *S* is the total surface area of the assembly, and *A* is total absorption within the room. The transmittance of a building element is equal to the transmission loss (TL) rating of a building element multiplied by the area of that element. Therefore, the lower the TL rating of a building element, or the greater the surface area of that building element, the greater the amount of noise that will transmit through the element.

Acoustically speaking, the windows and exterior doors are usually the weakest element in the structure, since more energy enters through them because they have less mass than the walls or the roof-ceiling structure. Once the windows are upgraded to the point where more energy enters the room through the walls and ceiling, then these structural components begin to require upgrading to achieve further noise reduction.

The transmission loss calculations conducted for this report were done according to the methodology found in the FHWA building insulation model.[4] This methodology uses the exterior-wall noise rating (EWNR) rating system, which is a single-number rating system that compares the laboratory measured noise reduction values at 16 one-third-octave bands against a standardized frequency curve, similar to the sound transmission class (STC) rating.

In the EWNR system, the frequency spectral curve against which the noise reduction data is compared places more emphasis on reducing low-frequency energy than does the STC curve. As a result, for a given transmission loss spectra for a tested building element, the EWNR rating is usually lower than the corresponding STC rating on the same data. The EWNR ratings for the windows and doors used in this analysis were obtained from test data provided by the manufacturers, and the ratings for the walls and roof-ceiling building elements were obtained from the methodology within the FHWA model. The corresponding STC ratings for the various building elements described in this analysis are included for comparison.

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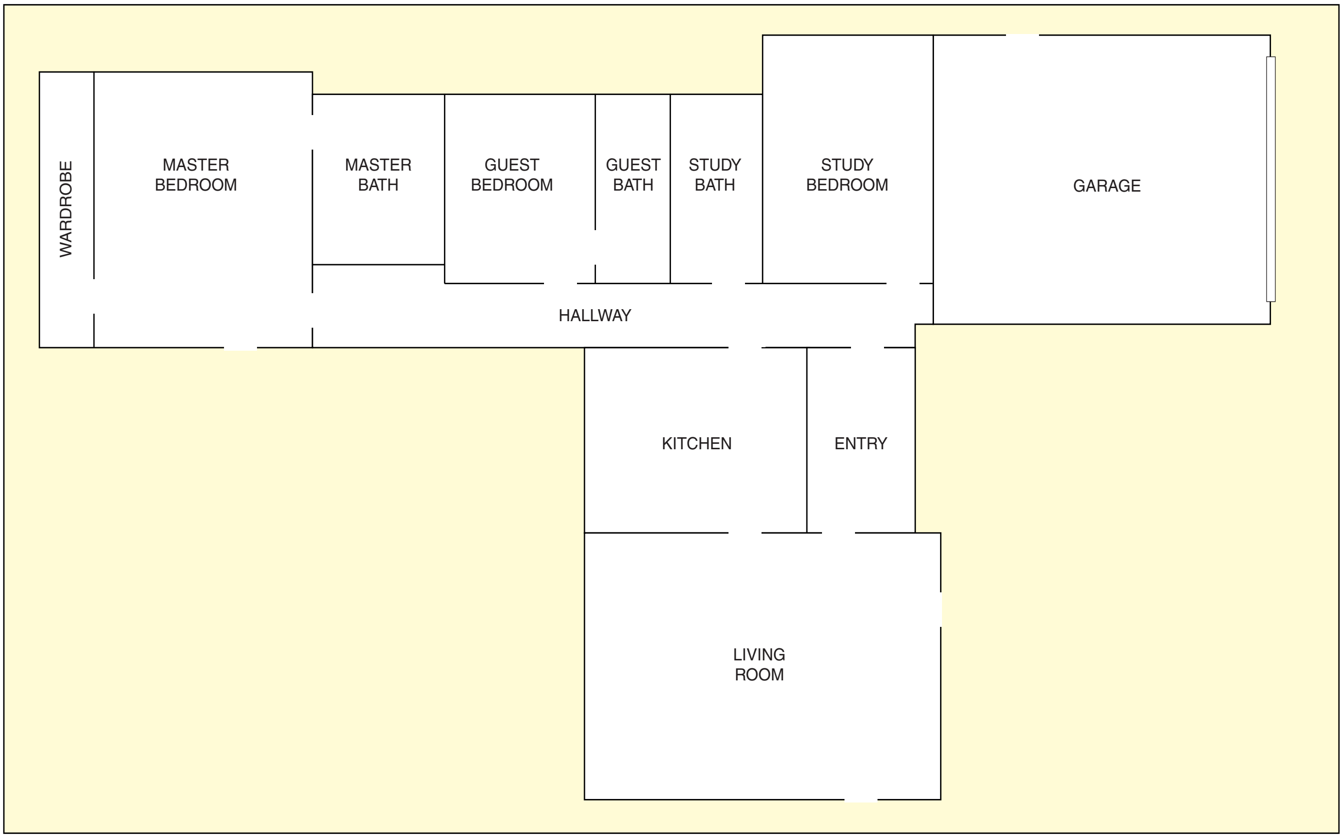

Figure 1. Project floor plan.

Existing Design

According to the architectural plans for the project, there are five habitable rooms within the proposed house that were used for calculation purposes. They include the master bedroom, the guest bedroom, the study/bedroom, the kitchen, and the living room as shown in the floor plan presented in Figure 1. The individual dimensions and building construction elements were taken from the architectural plans for each of the rooms being analyzed. The master bedroom has a floor area of 33.1 square meters and has two exterior walls separating the interior space from the exterior. The guest bedroom has a floor area of 21.9 square meters and one exterior wall separating the interior space from the exterior. The study/bedroom has a floor area of 26.5 square meters and one exterior wall separating the interior space from the exterior. The kitchen has a floor area of 28.8 square meters and one exterior wall separating the interior space from the exterior. The living room has a floor space of 68.4 square meters and has two exterior walls separating the interior space from the exterior.

The following are the construction details that were provided in the architectural plans for the project. These data were used to determine the outdoor-to-indoor noise reduction of each room type as originally designed.

- **Roof 1 – Open Ceiling**: Asphalt shingles over 16-mm oriented strand board (OSB) on roof trusses 610 mm on center; R-30 batt insulation; two layers of 16-mm gypsum board mounted to bottom of trusses. Noise rating: EWNR 37 (STC 41).
- **Roof 2 – Attic Space**: Asphalt shingles over 16-mm OSB on 51-mm × 254-mm rafters, 254 mm on center; 38-mm air gap over R-25 batt insulation; 22-mm-deep furring channels, 610 mm on center, secured to bottom of joists, two layers of 16-mm gypsum board mounted to furring channels. Noise rating: EWNR 39 (STC 43).
- **Wall**: 51-mm × 152-mm wood studs, 406 mm on center, with 89 mm batt insulation in all stud cavities; one layer of 6-mm Hardy shake composite shingles over 13-mm OSB on exterior, and two layers of 16-mm gypsum board on interior. Noise rating: EWNR 40 (STC 44).
- **Window**: Dual-paned windows. Noise rating (operable minimum): EWNR 24 (STC 26). Noise rating (fixed minimum): EWNR 26 (STC 28).
- **Doors**: French style with dual-paned windows. Noise rating (minimum): EWNR 19 (STC 22).

Using the dimensions from each room type along with the noise reduction values listed above, the outdoor-to-indoor noise reduction was calculated for each of the five room plans. The results of the analysis for existing conditions indicated that the interior noise level for each room would be:

- Master bedroom: 51.7 dB CNEL
- Guest bedroom : 45.3 dB CNEL
- Study: 46 dB CNEL
- Kitchen: 45.1 dB CNEL
- Living room: 49.6 dB CNEL

As initially designed, each of these rooms would exceed the interior noise level standard of 45 dB CNEL.

Required Building Upgrades

None of the rooms analyzed would meet the interior noise standard of 45 dB CNEL using the initial design building elements as described in the architectural plans. The transmission path for most of the acoustic energy within the rooms was determined to be either the windows or the exterior doors; so the first level of building upgrades was applied to these areas.

Upgrades for each area were determined based on the level of noise reduction required. For the master bedroom, the windows were upgraded to an EWNR rating of 31 (STC 33), and the French doors were upgraded to an EWNR rating of 35 (STC 37). The windows in the guest bedroom and the kitchen were upgraded to an EWNR rating of 28 (STC 32), and the windows in the study were upgraded to an EWNR rating of 29 (STC 33). The French doors in the living room were upgraded to an EWNR rating of 32 (STC 34).

The outdoor-to-indoor reduction of the five rooms were calculated with these upgrades, and the results are presented in Table 1. The table lists the room, the building element being upgraded, a description of the element construction, the noise reduction rating of that element, and the estimated interior noise level. With these upgrades, each of the rooms met the interior noise level of 45 dB CNEL. To achieve the interior noise level of 45 dB, only the windows and French doors require upgrading.

Optional Building Upgrades

Upgrades to Achieve 40-dB CNEL. The next step was to determine the specific building upgrades necessary to meet an interior noise level of 40 dB CNEL within each of the five rooms, which would require an outdoor-to-indoor noise reduction rating of 36. The upgrades needed to meet this rating were much more substantial, and they include upgrades to not only the windows and doors, but to the walls and to the roof-ceiling assemblies. The required noise reduction of the walls of the master bedroom and the living room were achieved by adding a layer of 13-mm shear paneling to the inside of the walls prior to installing the two layers of drywall.

For the master bedroom, the windows were upgraded to an EWNR rating of 39 (STC 43), and the French doors were upgraded to an EWNR rating of 40 (STC 44). For the living room, the windows were upgraded to an EWNR rating of 31 (STC 33), and the French doors were upgraded to an EWNR rating of 38 (STC 40). The windows in the guest bedroom, the study/bedroom, and the kitchen were upgraded to an EWNR rating of 33 (STC 35).

In addition to the lateral transmission paths, the roof-ceiling assembly for each of the rooms would have to be constructed using an insulated attic space and a flat ceiling. The ceiling portion of the assembly would be upgraded to include 22-mm-deep furring channels mounted 610 mm on center and secured to the bottom of the ceiling joists, and 2 layers of 16-mm gypsum board mounted to the furring channels. The specific building upgrades necessary to meet an interior noise level of 40 dB CNEL are listed in Table 2. Included in the construction detail of the table are some window manufacturers and their product lines that have the necessary window ratings required to meet the given noise standard.

Attic spaces on sloped roofs are usually vented to reduce the level of heat accumulating within the attic. To reduce the level of noise entering the attic space through the vents, all would need acoustic baffles installed in them. A detailed drawing of one type of attic vent baffle that was recommended for this application is presented in Figure 2. This vent was designed specifically to provide sufficient airflow into the attic space while providing mitigation to exterior noise entering the attic space through the vent.

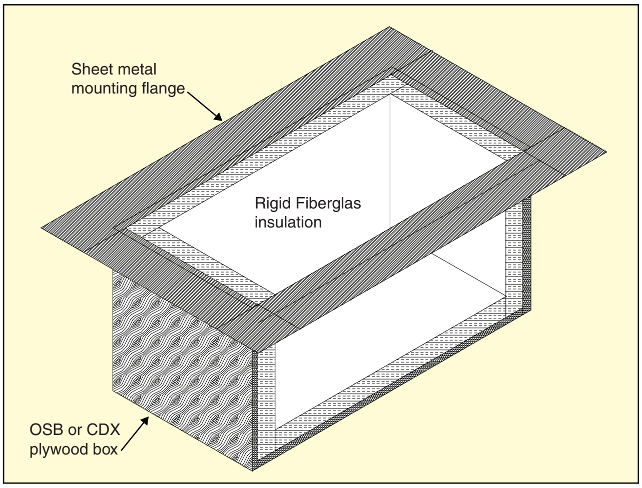

Figure 2. Attic vent noise baffle.

Upgrades to Achieve 35 dB CNEL. The specific building upgrades necessary to meet an interior noise level of 35 dB CNEL were then calculated for all five rooms, and the results are listed in Table 3. The upgrades listed in this table are even more substantial than those listed in Table 2. The roof of the master bedroom would need to be upgraded beyond what was shown in the architectural plans. It would require an additional layer of 19-mm plywood sheathing on top of the trusses as well as finishing the roof with either clay or concrete tiles. These items would be required to increase the mass of the roof structure to further reduce the level of noise provided by the asphalt shingles currently proposed.

The exterior walls of the house would also have to be upgraded from 51 mm × 152 mm single-stud assemblies to 51 mm × 152 mm staggered-stud assemblies. This would not change the thickness of the wall from what is currently proposed, but it would result in the separation of the exterior wall panels from the interior wall panels. This would increase the noise reduction of the overall assembly by about 10 dB. Here are the construction details of the proposed exterior walls:

- Hardi shingles
- One layer of 13-mm plywood sheathing
- 51 mm × 102 mm staggered stud walls, 406 mm on center, on

Table 1. Building upgrades needed to meet 45-dB CNEL.

Room	Building Element	Construction	Noise Rating, EWNR/STC	Indoor Level, dB CNEL
Master BR	Windows	Dbl-pane glass	31/33	44.9
	French doors	Solid core with dbl-pane glass	35/37	
Guest BR	Windows	Dbl-pane glass	28/32	43.9
Study/BR	Windows	Dbl-pane glass	29/33	43.8
Kitchen	Windows	Dbl-pane glass	28/32	43.9
Living Rm	French doors	Solid core with dbl-pane glass	32/34	44.5

Table 2. Building upgrades needed to meet 40-dB CNEL.

Room	Building Element	Construction	Noise Rating, EWNR/STC	Indoor Level, dB CNEL
Master BR	Roof	Attic vent baffle	45/49	39.9
	Wall	Add 1 layer of shear paneling on interior	41/45	
	Windows	Milgard 7520 series	39/43	
	French doors	Not found	40/44	
Guest BR	Roof	Attic space, attic vent baffle	45/49	39.3
	Windows	Milgard 5320 series	33/35	
Study/BR	Roof	Attic space, attic vent baffle	45/49	39.8
	Windows	Milgard 5320 series	33/35	
Kitchen	Roof	Attic space, attic vent baffle	45/49	39.5
	Windows	Milgard 5320 series	33/35	
Living Rm	Roof	Attic space, attic vent baffle	45/49	39.9
	Wall	Add 1 layer of shear paneling on interior	41/45	
	Windows	Summit 8650 series	31/33	
	French doors	West Coast vinyl 4500	38/40	

Table 3. Building upgrades needed to meet 35-dB CNEL.

Room	Building Element	Construction	Noise Rating, EWNR/STC	Indoor Level, dB CNEL
Master BR	Roof	Clay/concrete tiles, additional plywood sheathing, attic space vent baffle	48/52	34.9
	Wall	Staggered-stud wall	52/54	
	Windows	Milgard 7120 series	43/46	
	French doors	Not found	40/44	
Guest BR	Roof	Attic space, attic vent baffle	45/49	39.3
	Windows	Milgard 5320 series	33/35	
Study/BR	Roof	Attic space vent baffle	45/49	34.8
	Wall	Staggered-stud wall	52/54	
	Windows	Milgard 7320 series	39/43	
Kitchen	Roof	Attic space vent baffle	45/49	34.9
	Wall	Staggered-stud wall	52/54	
	Windows	Milgard 7320 series	39/43	
Living Rm	Roof	Attic space vent baffle	48/52	34.8
	Wall	Staggered-stud wall	52/54	
	Windows	Milgard 5320 series	33/38	
	French doors	Not found	43/47	

51 mm × 152 mm plates
- R-13 batt insulation in all stud cavities
- One layer of 16-mm plywood sheathing
- Two layers of 16-mm gypsum board
- Noise rating: EWNR 52 (STC 54)

The windows in the master bedroom would need to be upgraded to an EWNR rating of 43 (STC 46). The windows in guest bedroom, the study, and the kitchen would all have to be upgraded to an EWNR rating of 39 (STC 43). The windows in the living room would have to upgraded to an EWNR rating of 33 (STC 36). Commercially available windows were found that met the required ratings for each of the rooms within the house. The French doors leading to the master bedroom would have to be upgraded to an EWNR rating of 45 (STC 49), and the French doors for the living room would have to be upgraded to an EWNR rating of 43 (STC 46). By incorporating these recommended building upgrades, the interior noise level of each room was shown to meet the interior level of 35 dB CNEL.

Construction details

Proper construction and installation techniques are required for the components to achieve the specified noise reduction values. To that end, the following notes were included to ensure that the noise rating designed was the noise rating actually achieved:
- All window and door assemblies must be installed according to the manufacturers' requirements and recommendations.
- Perimeter of gypsum board walls and ceiling assemblies shall be caulked airtight with non-drying, non-hardening caulking compound prior to taping.
- There shall be no rigid connections between the opposite sets of studs within the staggered stud walls. The framing shall be inspected to ensure that all horizontal framing supports connecting the two separate wall assemblies within the staggered stud wall are removed. They shall not bridge the gap separating the walls.
- Utility outlets (electricity, television, and telephone) in staggered-stud wall assemblies should be staggered at least 610 mm from any penetrations on the opposite side so there are no back-to-back penetrations. All outlet boxes should be sealed and insulated from the wall cavity by being completely wrapped with dense pads (Lowry #10 pads or equivalent). The openings in the drywall for the outlet boxes shall be as small as possible, and sealed around the perimeter with resilient caulking.

Conclusions

The analysis showed that all of the rooms within the proposed home can be upgraded to meet the interior noise standard of 45 dB CNEL by incorporating upgraded windows in all rooms, and upgraded French doors in the master bedroom and in the living room. All of the rooms can be upgraded to achieve an interior noise standard of 40 dB CNEL by incorporating substantial upgrades to the windows, doors, walls, and roof-ceiling assemblies. All of the rooms within the home could achieve an interior noise standard of 35 dB CNEL; however, they would require incorporating extensive building upgrades that far exceeded the initial design of the structure.

Acknowledgements

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