# 5 Traffic Noise Abatement

As is generally accepted, the negative perception of noise is defined as annoyance and the positive perception of noise is defined as comfort. Today there is a need to handle noise at source and to rate it correctly, exploring the physical and psycho-acoustic aspects and also the impact of visual aesthetics on the soundscape (Canévet 1996; Fyhri and Klaeboe 1999).

Noise has an important environmental impact with short- and long-range effects on human communities, on nature and on wildlife (Carlson et al. 1977; Marquis-Favre et al. 2005). Ambient noise is "the all-encompassing noise associated with any given environment, and is usually a composite of sounds from many sources – near and far" (Harris 1998). A description of the noise environment in the audible range, outdoors, is provided by the A-frequency weighted day and night average sound level. The noise description should include a map (Piccolo et al. 2005), drawn in increments of 5 dB, representing the contours of constant values of the yearly day–night average sound level or day–night sound exposure, for the existing conditions. Different methods, which relate the human response to noise, have been used to ascribe a numerical degree of impact on the population (loudness, annoyance, speech interference, hearing loss, etc.). As noted by Bishop and Schomer (1998; Table 5.1), the range of variation in outdoor day–night average sound levels in urban communities is very big. Figure 5.1 shows the A-weighted sound level in early afternoon and

**Table 5.1.** Variation of the outdoor day–night average sound levels in urban communities in the United States (Bishop and Schomer 1998). Reprinted with permission of the Acoustical Society of America, copyright 2005

| Sound level (dB) | Number of people (millions) | | | | | |
|---|---|---|---|---|---|---|
| | Traffic only | Traffic and aircraft | Traffic and construction | Traffic and rail | Traffic and industrial | Total |
| > 80 | 0.1 | 0.1 | – | – | – | 0.2 |
| > 75 | 0.9 | 0.5 | – | 0.1 | – | 1.5 |
| > 70 | 4.5 | 2.2 | 0.2 | 1.0 | 0.2 | 8.1 |
| > 65 | 15.2 | 7.6 | 0.8 | 3.0 | 1.2 | 27.8 |
| > 60 | 36.6 | 16.1 | 2.8 | 4.4 | 3.7 | 63.6 |
| > 58 | 49.2 | 24.3 | 6.0 | 6.0 | 6.9 | 92.4 |

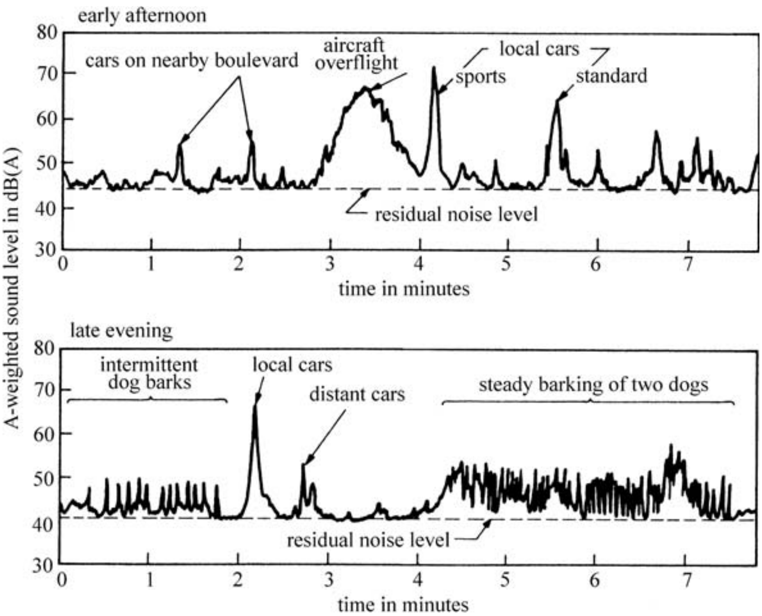


**Fig. 5.1.** Early afternoon and late evening measurements of A-weighted sound levels of outdoor noise versus time in an suburban area, using a microphone located at 6.1 m from the street curb (Bishop and Schomer 1998). Reprinted with permission of the Acoustical Society of America, copyright 2005

late evening in a residential area. Distinct noise events can be observed in this figure, such as for example local cars, aircraft overflight, or intermittent dog barks.

The Green Paper on future noise policy (European Commission 1996) noted that "the environmental noise, caused by traffic, industrial and recreational activities, is one of the main local environmental problems in Europe and the source of an increasing number of complaints for the public". Over the years, since the second half of the 20th century, a considerable amount of research and development activity was carried out into the noise problem. In more than 50 years, noise at source has been reduced by a considerable amount. Numerous standards and regulations impose noise control and limitation. At the same time, the traffic volume is increasing continuously, as well as people's expectation for quietness. Noise annoyance is fundamentally a matter of public perception. As an example, Table 5.2 gives an assessment of the overall impact of urban traffic noise in excess of 55 dB, in the United States. A reduction of 5 dB in the day–night level represents an improvement of 68%, while a reduction of 10 dB represents an improvement of 89%.

Noise acceptability criteria are difficult to establish, because so much depends on the circumstances of each individual case, which also supposes a sub-

**Table 5.2.** Overall impact of urban traffic noise on population in the United States (von Gierke et al. 1998). Reprinted with permission of the Acoustical Society of America, copyright 2005

| Estimate of current conditions | | Annoyance-weighted population | | | Population-weighted day–night sound exposure (1,000 Pa s$^2$) | | |
|---|---|---|---|---|---|---|---|
| Day–night contour levels | Population within each contour | Current | For day–night level reduction of: | | Current | For day–night level reduction of: | |
| dB | Millions | 0 dB | 5 dB | 10 dB | 0 dB | 5 dB | 10 dB |
| 50–55 | 37.0 | 3.3 | 1.8 | 0.7 | 228 | 72 | 72 |
| 55–60 | 34.7 | 6.3 | 3.1 | 1.7 | 674 | 213 | 67 |
| 60–65 | 17.4 | 5.6 | 3.1 | 1.6 | 1,070 | 338 | 107 |
| 65–70 | 5.6 | 3.0 | 1.8 | 1.0 | 1,088 | 344 | 109 |
| 70–75 | 1.2 | 1.0 | 0.7 | 0.4 | 738 | 233 | 74 |
| 75–80 | 0.1 | 0.1 | 0.1 | 0.1 | 194 | 62 | 19 |
| Total | 96.0 | 19.3 | 10.6 | 5.5 | 3,992 | 1,262 | 448 |
| Noise impact index | | 0.2 | 0.1 | 0.06 | – | – | – |
| Reduction | – | – | – | – | – | 68% | 89% |

jective approach. In most practical situations, the costs of noise control versus the environmental consequences must be taken into consideration. Most residential environments are affected by more than one noise source. Decreasing the level of a steady noise of 1 dB or less is detectable only in laboratory conditions. Noise annoyance generally increases with noise level. Variations of 5 dB are realistic under real-life conditions, for which the noise sources (aircraft, railway or road traffic) are not steady. Different technical methods of assessment are available; and it is important that these should be carefully selected to mach the precise objectives of the assessment in each particular case. Always, it is useful to support the best compromise solution that can be achieved.

The environmental noise impact depends on the total energy received at the observation point, the rate of occurrence of noise events and the magnitude of any noisier single event. The statistical description of community noise (Kinsler et al. 1982) is based on the A-weighted measurement of different parameters, as noted in Chap. 4.

The highest community noise rarely exceeds 80 $L_{\mathrm{eq}}$ or 120 $L_{A_{\max}}$ (the maximum time-weighted level). Typical levels of community noise caused by traffic or noisy neighbors are in the range of 45–75 $L_{A_{\mathrm{eq}},16\mathrm{h}}$ (for 16 h time-long term linear averaging).

The reduction of noise level requires the following three main steps: the evaluation of the noise environment under existing conditions, the determination of the acceptable noise level and the determination of the difference between the two previous steps.

In urban communities, the sources of noise are numerous and may include noise produced by highways, rail and aircraft transportation. The techniques for noise control are related to control at the source, at the receiver and at the transmission path. The source, the receiver and the transmission path are continuously interrelated. The output of the noise source, which is never constant, depends on the environment in which the source is located. At the same time, the response of the receiver depends upon the characteristics of the path and source.

Noise control at the source can be operated by reducing the amplitude of the vibrations, by reducing the motion of the components into vibration, or by using damping materials. Noise reduction can also be obtained by controlling and reducing the transmission path:

- by reducing the energy transmitted to the receiver (for example: by increasing the distance between the source and the receiver, by altering the relative orientation of the source and receiver, by taking advantage of the natural topography and wind, etc.);
- by introducing barriers of a large size compared with the wavelength of the noise source (for example: by reflection, the noise field of jet aircraft engines can be oriented toward the sky);
- by enclosures around the noise source and receiver.

Noise abatement measures and noise control in communities and industries has become in large part a matter of law. The noise is a parameter of the quality of the acoustical environment which has to be included into the planning process and to be analyzed in an environmental impact statement.

The main outdoor sources of noise in modern life, which significantly affect the quality of human environment, are generated by traffic on the streets or highways, by rail transportation and by aircraft. The synthesis of social surveys on noise annoyance published by Schultz (1978) demonstrated that correlations exist between the degree of exposure to the noise and the intensity of annoyance felt by the subjects.

A combination of plant materials (trees, belt of trees, shrubs and a soft surface of grass or other plant materials throughout the area) and specific topographic situations may provide some immediate improvement in noise abatement, with the likelihood of better conditions as the plants mature.

## 5.1 Road Traffic Noise

Models of different complexity (Attenborough 1982; Steele 2001) have been used for traffic noise prediction since 1950. Earlier models (which are obsolete today) were designed to predict a single vehicle sound pressure level ($L_\mathrm{P}$) at the roadside, with the assumption that the vehicle had a constant speed. Later models were developed for the equivalent continuous level ($L_{eq}$) for traffic over a chosen period, under interrupted and varying flow conditions, with linear, A-weighted levels and one-third octave band spectra. The studied sources were single points, short line sources, double point sources, or multiple point sources with different spectra. As suggested by Steele (2001), the ideal model proposed a source composed by a multi-stream (branched and interlocked streams of vehicles), with a source/receiver weighting, with octave/dB(A) determining $L_{eq}$, $L_N$, $L_{min}$, $L_{max}$.

The tendency to unify noise calculation algorithms in Europe was realized with the standards ISO 9613-2 (1996) and EN 1793-3 (1997). A procedure to find automatically all relevant sound paths in an arbitrary two-dimensional terrain for road traffic noise was developed by Heutschi (2004). A-weighted excess attenuation of a highway traffic line source with ground type was discussed by Attenborough (1982). Meteorological factors and ground conditions influence sound propagation over open ground and it is difficult to differentiate ground effects from other outdoor measurements. The forest floor is a soft floor for which the excess attenuation increases with the horizontal distance from source line to receiver.

A typical situation for the description of road traffic noise and the possible attenuation by a belt of trees and barriers is synthesized in Fig. 5.2. The first option uses only distance as a means of noise attenuation. The second option uses tunnels and a belt of vegetation. The third option uses the natural site topography, creating a corridor for automobile and truck traffic. The belt of trees is between the corridor and the buildings. The fourth option uses earth mounds, on which trees are planted. The fifth option uses different types of barriers. The following three options are combined solutions for traffic noise reduction. The attractive visual appearance of a belt of trees can affect the perception of traffic noise (Watts et al. 1999).

Heavy trucks are the most important noise generators on highways. Table 5.3 gives the octave-band sound pressure level for heavy trucks and automobiles for two speeds (56 km/h and 88 km/h) measured at 1.2 m above the ground and 15 m distance from the source (Bowlby 1998). The heavy trucks travelling at 88 km/h produced an A-weighted sound level of 87.5 dB(A), which is about 20% higher than that produced by automobiles travelling at the same speed.

Figure 5.3 gives data on traffic noise reduction by two belts of trees, (deciduous trees and bushes), one of 19 m width, the other of 25 m width, compared with a corn field. The excess attenuation in one-third octave bands shows a maximum around 500 Hz, which is probably due to the interference between the directly transmitted wave and the reflected wave from the ground and the belt of trees. The increasing attenuation between 2 kHz and 4 kHz can be attributed to the branches and leaves (Kragh 1981). In this experimental configuration, no significant differences were observed between $L_{A_{eq}}$ at 1.5 m above

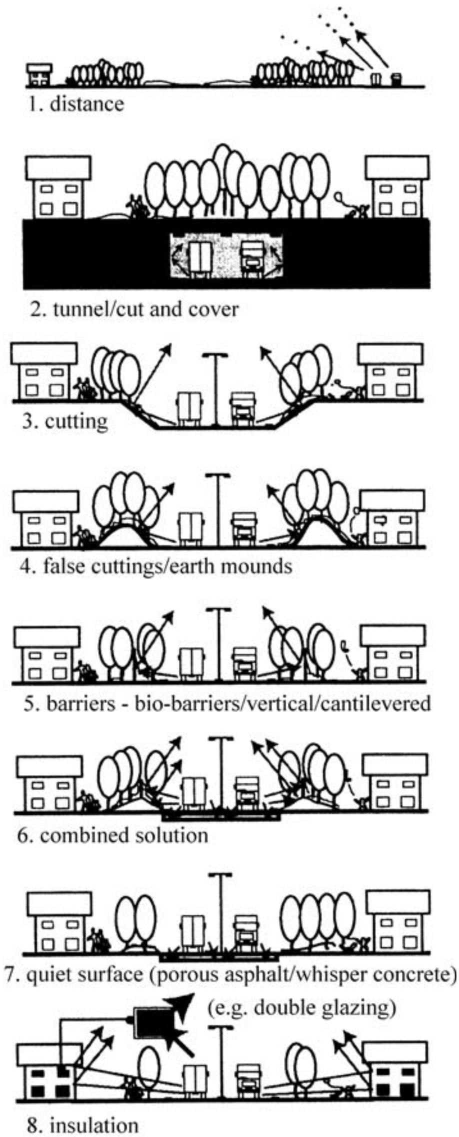


**Fig. 5.2.** Road traffic attenuation with belt of trees and different barriers (Kotzen 2004)

grass-covered ground and through the belt of trees, probably because only one parameter is not sufficient to express the complexity of the experimental situation.

Figure 5.4 shows the propagation of noise over a forest stand composed of parallel bands of Norway spruce and red pine and having the edge limited by a road and a row of deciduous trees. The variation in sound pressure

**Table 5.3.** Octave-band sound pressure level for heavy trucks and automobiles for two speeds measured at 1.2 m above the ground and 15 m distance from the source (Bowlby 1998). Reprinted with permission of the Acoustical Society of America, copyright 2005

| Speed (km/h) | Octave-band center frequency (Hz) 125 | 250 | 500 | 1,000 | 2,000 | 4,000 | A-weighted sound level dB(A) |
|---|---|---|---|---|---|---|---|
| | | | | Heavy trucks | | | |
| 56 | 87 | 84.5 | 81.5 | 78 | 74.5 | 70.5 | 83.5 |
| 88 | 87.5 | 85 | 87.5 | 82.5 | 77 | 73.5 | 87.5 |
| | | | | Automobiles | | | |
| 56 | 65 | 61 | 62 | 61 | 57 | 53 | 65 |
| 88 | 71 | 68 | 66 | 68 | 66 | 60 | 72 |

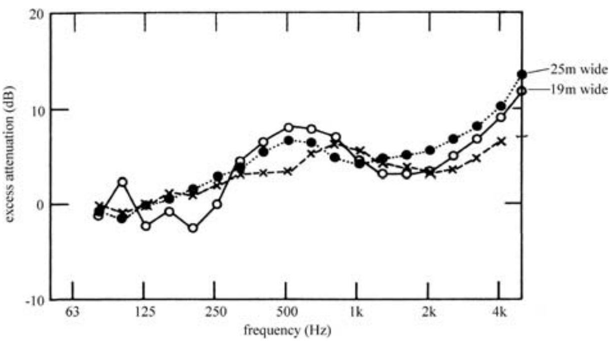


**Fig. 5.3.** Excess attenuation versus frequency in one-third octave bands for a belt of trees (Kragh 1981). Reprinted with permission from Elsevier. ○ Tree belt 19 m wide, ● tree belt 25 m wide, × corn field

level versus distance clearly shows the important attenuation induced by the forest stand. The important attenuation in the forest stand due to scattering by trunks can be seen at 1.65 m (5 ft). The effect of foliage is observed at 5 m height (15 ft). Above the top of the canopies, at 14.85 m (45 ft), the attenuation is not influenced by distance in the forest stand. A strong attenuation with distance was observed with measurements between 8.25 m and 11.5 m (25 ft and 35 ft), within the canopy.

The impact of traffic noise on $L_{10}$ and $L_{95}$ measured in a big urban park of English style (153,500 m$^2$) situated in the center of a very noisy city (Athens, in Greece) showed that a reduction of 4 dB(A) was induced by the dense vegetation of shrubs and trees, at a distance of 20–40 m from the garden perimeter (Papafotiou et al. 2004). Also in Europe, the city of Geneva in Switzerland developed an outstanding policy of parks development since 1863 (Beer 1996), having today 40,000 trees, of which 85% are situated in parks and 15% along avenues and in public squares, to which must be added more than 30,000 trees on private property; and 20% of the urban surface is covered by parks. More than 350 species have been recorded, of which 50 are indigenous. Muir (1984) studied the silvicultural criteria for the selection of trees

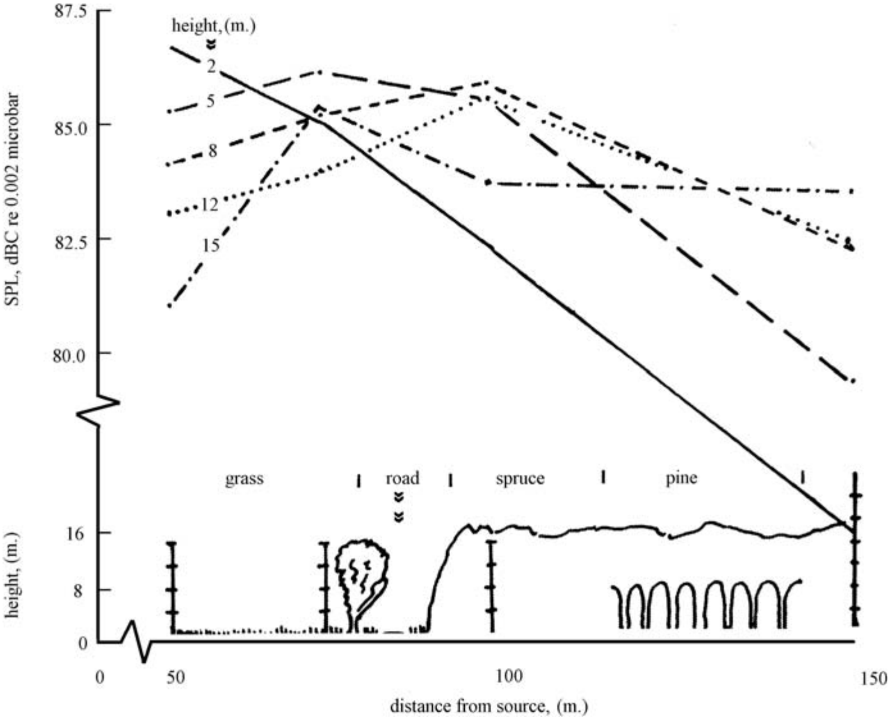


**Fig. 5.4.** Noise propagation over a forest stand composed of parallel bands of Norway spruce and red pine and having the edge limited by a road and a row of deciduous trees (Herrington and Brock 1977)

in urban and suburban areas, such as the growth requirements of each tree species, silvicultural background and specific features which can be evaluated for individual trees and stands. Air, water, minerals and sunlight are necessary to maintain tree growth. Parameters such as age, height, diameter at breast height, growth rate, live crown ratio, density/number of stems per unit area, defects/scars, insect damage, disease, mushrooms on the stem, etc. and general sanitary state are important for a silvicultural evaluation of trees.

Street trees have an important effect on summer micro-climate and noise abatement (Mao et al. 1993). Figure 5.5 gives an example of the arrangements of trees of different species in two streets in Nanjing City in China, in which vehicle lanes, bicycle lanes and sidewalks coexist. Depending on species, the attenuation efficiency varied between 0.1 dB/m and 0.36 dB/m (Table 5.4).

The structure and composition of street-side trees in residential areas depends on site plans, the socio-economic status of the residents and individual preferences for street-side vegetation (Zipper et al. 1991).

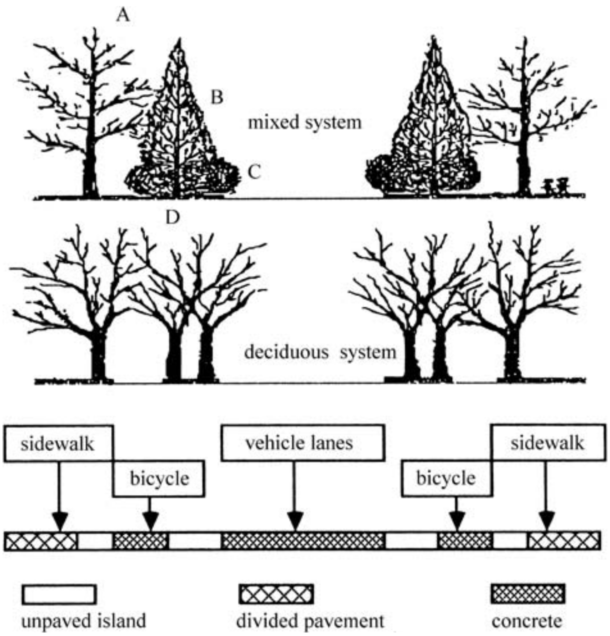


**Fig. 5.5.** Arrangement of trees and traffic lanes in two streets in Nanjijg, China (Mao et al. 1993). *A* = *Carya illinoensis*, *B* = *Cedrus deodara*, *Metasequoia glyptostroboides* or *Sabina chinensis*, *C* = *Pittosporum tobira* and *Euonymus japonica*, *D* = *Platanus x acerifolia*

**Table 5.4.** Some characteristics measured in four streets in Nanjing in China (Mao et al. 1993)

| Characteristics | Streets | | | |
|---|---|---|---|---|
| | No. 1 | No. 2 | No. 3 | No. 4 |
| Street width (m) | 40 | 42 | 28 | 30 |
| Species | Deciduous | Mixed | Deciduous | Mixed |
| Number of tree rows | 6 | 4 | 2 | 4 |
| Width of green belt (m) | 35 | 35 | 28 | 26 |
| Canopy height (m) | 4–25 | 4–22 | 4–25 | 4–20 |
| Crown projection (%) | 80–85 | 80–85 | 80–90 | 80–85 |
| Noise attenuation dB(A) | 6 | 4 | 1 | 8 |
| Efficiency | 0.24 | 0.31 | 0.10 | 0.36 |
| Species | *P. x acerifolia* | *M. glyptostr.*<br>*S.chinesis*<br>*P. tobira*<br>*C. illinoensis*<br>*E. japonica* | *P. x acerifolia* | *M. glyptostr.*<br>*C. deodara*<br>*C. illinoensis* |

Reduction of noise annoyance in modern urban zones can be improved by a new approach on the environmental acoustics of urban open space, proposed by Ge and Hokao (2004). The importance of urban park soundscape management has been pointed out, by exploring the relations between the soundscape of urban parks and the external environment. In the park soundscape, the main disagreement is introduced by traffic noise. Preventing the traffic noise from intruding into parks and minimizing the negative influence of noisy everyday activities can be obtained with an appropriate landscape design, as can be seen from Fig. 5.6. Protection and regeneration of the natural environment leads to the development of the components of natural sounds, which are the sounds produced by birds and insects chirping, foliage tree rustling and water flowing and jetting. The woody zone acts as a buffer area for the traffic noise, for the benefit of noise-proofing.

The woodlands in urban areas can originate from large woodland blocks which survived urbanization, from planted belts of trees and shrubs or from the spontaneous regeneration of woodland communities on derelict sites. "The urban woodlands are of immense value to the local community – they offer a temporary oasis from the noise and stress of urban life" (Cole and Mullard 1982). Also, trees have considerable aesthetic appeal and an important cultural impact as an educational resource (outdoor classroom for biological and ecological studies, improving community social life, etc.).

As noted by the USDA Agroforestry Center (2004), trees can be used as noise buffers, able to reduce noise by 5–10 dB, following some general recommendations, such as:

- plant the noise buffer close to the noise source, rather than close to the area to be protected;
- plant trees/shrubs as close together as the species will allow without being overly inhibited;
- when possible use plants with dense foliage: a diversity of tree species, with a range of foliage shapes and sizes within the noise buffer may also improve noise reduction;
- foliage of the plants should persist from the ground up: a combination of shrubs and trees may be necessary to achieve this effect;

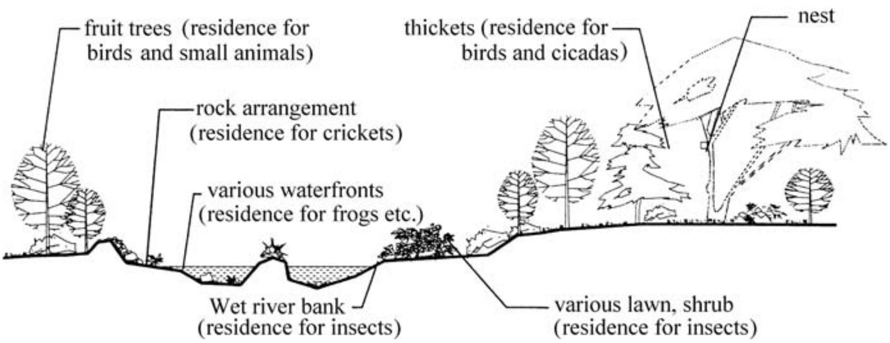


**Fig. 5.6.** Trees of different species and bushes for the improvement of the soundscape in urban parks (Ge and Hokao 2004)

- evergreen varieties that retain their leaves will give better year-round protection;
- when possible use taller plants. Where the use of the tall trees is restricted, use combinations of shorter shrubs and tall grass or similar soft ground cover, as opposed to harder paved surfaces.

To reduce the noise of moderate traffic in communities:

- plant belt trees 7–17 m wide along roadsides;
- plant the nearest edge of the belt within 7–17 m of the center of the nearest traffic lane;
- use 2–3 m shrubs next to the road and back-up tree rows a minimum of 4–7 m tall when mature;
- the length of the tree belt should be twice as long as the distance from the road to the recipient of the noise;
- the buffer should also extend an equal distance in both directions parallel to the road.

To reduce heavy vehicle noise in suburban or rural areas:

- plant belts of trees 20–35 m wide along roadsides;
- plant the nearest edge of the belt within 20–25 m of the center of the nearest traffic lane;
- use 2–3 m shrubs next to the road and back-up tree rows a minimum of 15 m tall at the center row;
- the length of the tree belt should be twice as long as the distance from the road to the recipient of the noise;
- the buffer should also extend an equal distance in both directions parallel to the road.

## 5.2 Rail Transportation Noise

Rail transportation is one of the most used systems through the world for passengers and freight within urban and suburban areas and between cities. The principal sources of noise are produced by the propulsion system of the railcars and locomotives, by the interaction between the wheels and the rail and by aerodynamics-connected phenomena (Hanson et al. 1998). The noise produced by rail transportation is expressed in terms of sound pressure levels at a standard distance from the track (30 m) and at a standard height above the ground (1.5 m).

Figure 5.7 illustrates the variation of the A-weighted sound level during 30 s corresponding to the pass-by of a locomotive-hauled passenger train at 30 m,

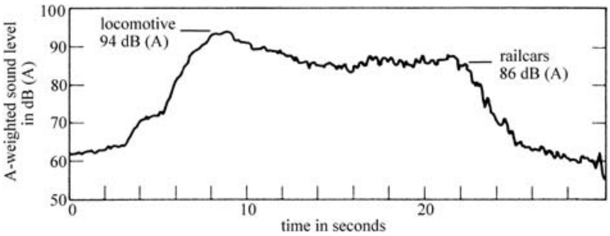


**Fig. 5.7.** Variation in noise level versus time (10 s) during pass-by of a locomotive-hauled passenger train travelling at 114 km/h (Hanson et al. 1998). Reprinted with permission of the Acoustical Society of America, copyright 2005

travelling at 114 km/h. The locomotive is located at 94 dB(A) and the railcars at 86 dB(A). The noise source is different for welded rail and for jointed rail.

The relationship, which predicts an increase in A-weighted sound level of 9 dB(A) per doubling of car speed, between the A-weighted sound levels and the speed of the train travelling *on continuous welded rail* is:

$$L_A = 75 + 30 \log_{10} \frac{V}{V_0} \quad [\text{in dB(A)}] \tag{5.1}$$

where $V$ is the railcar speed (km/h) and $V_0$ is the reference speed (60 km/h).

When the train is travelling on *jointed rail*, the relationship between $L_A$ and the railcar speed is:

$$L_A = 79 + 30 \log_{10} \frac{V}{V_0} \quad [\text{in dB(A)}] \tag{5.2}$$

In urban zones, trains of railcar-size passenger vehicles with rubber tires are also largely used. These trains operate at relatively low speed, 60 km/h. Because of their electrical and mechanical equipment, the noise levels produced by these types of trains are similar to each other.

Rail systems generate groundborne vibrations which are important and depend on the resonance frequencies of the train suspension systems and the smoothness of the wheels and rails.

The main desiderata of modern acoustic research are related to the reduction of noise annoyance from 91 dB(A) to 83 dB(A) for high-speed trains and a reduction between 20 dB(A) and 10 dB(A) for freight within urban and suburban areas (Gautier et al. 2004).

Railway noise, which is short and abrupt, recurring only after a long period, is different from road traffic noise, which is mostly continuous and has short periods of discontinuity (Raimbault et al. 2004). Human subjects recognize railway noise as related to specific time-patterns, characterized by the identification of the noise source, whereas road traffic noise is related to a description related to the space generating the noise. Environmental factors and visibility can enhance or mask noise loudness (Mulligan et al. 1987; Watts et al. 1999). At the same time, the variability in the perception of noise loudness is related to the individual sensibility of subjects (Mace et al. 1999).

The influence of meteorological conditions on the noise attenuation of rail transportation is mentioned in the French standard AFNOR XP S31-133 (2001).

Rail noise reduction by the belt of trees was studied by Kragh (1979). The experimental arrangement is shown in Fig. 5.8 for two distances between the microphones, namely 68 m (case 1) and 40 m (case 2). In the first case (Fig. 5.8a), the rails were 0 to 0.5 m below terrain. The tree belt was of a finite length of 400 m, composed of 50-year-old birches and elms mixed with lower 15-year-old beeches and confers. The position of the microphones is indicated in the figure. The track consisted of welded rails on rubber plates on wooden sleepers in stone ballast. In the second case (Fig. 5.8b), the belt was 1,200 m long and

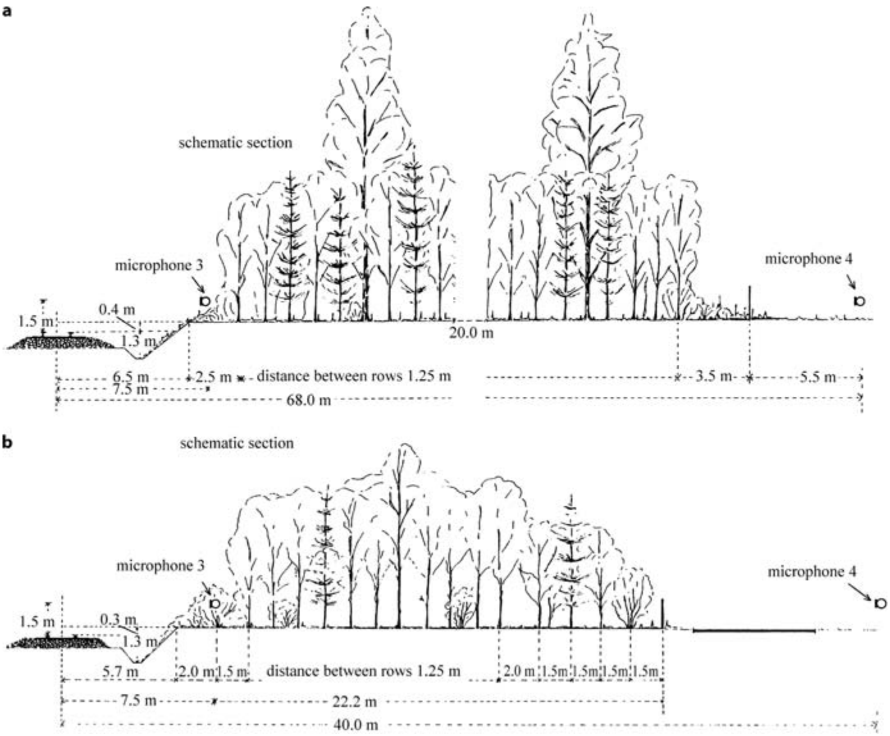


**Fig. 5.8.** Experimental arrangements for sound level measurement from passing trains and attenuation measurements through belts of trees and bushes. Reprinted from Kragh (1979), Copyright 2005, with permission from Elsevier. **a** Belt profile and measurements for 68 m distance between the microphones, **b** belt profile and measurements for 40 m distance between the microphones

25 m wide, composed of 20-year-old oaks mixed with hornbeams, poplars and silver firs, and bushes. The track consisted of 30-m lengths of jointed rails, directly on wooden sleepers in stone ballast.

Noise from the same train passing by was recorded in two positions, at the reference section of the track and at the belt positions. Noise from 15 pass-bys was recorded during 8 h at each site. In the laboratory, for each microphone position, the $L_{A_{eq}/60s}$ was determined for each microphone. The A-weighted sound pressure levels were determined. The difference was calculated between $\Delta L_{A_{eq}}$ and $L_{A_{eq}}$ at positions 1 and 2 and positions 3 and 4. The difference $\Delta(\Delta L_{A_{eq}})$ was calculated at shelter belt positions 3 and 4 above the reference attenuation at positions 1 and 2 (Table 5.5). As can be seen from this table, the main value of $\Delta(\Delta L_{A_{eq}})$ at site 1 was 9 dB(A), with a standard deviation of 1.4 dB(A) and 6 dB(A) at site 2.

Wheel/rail noise had a major contribution to the overall noise level.

A definitive conclusion is difficult to draw from this experiment, because firstly the source of noise was not identical at sites 1 and 2 and secondly the site configurations had minor differences. In any case, it can be stated that the attenuation effect of belt vegetation is combined with terrain configurations. In the first case, behind a dense belt, 15 years old, 50 m wide, composed of beeches and various conifers planted between older birches and elms, noise levels were 8–9 dB(A) lower than in level grass-covered country. In the second

**Table 5.5.** Acoustic characteristics measured in two experimental sites (Kragh 1979). Reprinted with permission from Elsevier, copyright 2005. Locomotive type: diesel electric; cars: $p$ = passenger coaches, $g$ = goods wagons

| Site | Loco. type | Cars | Speed | $L_{A_{eq}}/60s$ [dB(A)] | | | | $\Delta L_{A_{eq}}$ [dB(A)] | | $\Delta(\Delta L_{A_{eq}})$ [dB(A)] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (no./type) | (km/h) | Pos. 1 7.5 m | Pos. 2 55 m | Pos. 3 7.5 m | Pos. 4 68 m | 1 & 2 | 1 & 3 | 3,4 & 1,2 |
| No. 1 | MY | 4p | 105 | 85.4 | 74.2 | 86.4 | 64.5 | 11.2 | 21.9 | 10.7 |
| (Fig. 5.8a) | MV | 10g | 85 | 81.8 | 70.0 | 82.4 | 60.2 | 11.8 | 22.2 | 10.4 |
| Average site 1 for 13 trains | – | – | – | – | – | – | – | 13.4 | 22.4 | 9.1 |
| Standard deviation | – | – | – | – | – | – | – | 1.7 | 0.4 | 1.4 |
| No. 2 | MY | 4p | 108 | 88.3 | 78.7 | 92.4 | 74.3 | 9.6 | 18.1 | 8.5 |
| (Fig. 5.8b) | MY | 12g | 79 | 89.3 | 75.6 | 90.4 | 73.1 | 13.7 | 17.3 | 3.6 |
| Average site 2 for 15 trains | – | – | – | – | – | – | – | 12.4 | 18.3 | 15.9 |
| Standard deviation | – | – | – | – | – | – | – | 1.7 | 0.7 | 1.8 |

case, behind a dense belt, 10–20 years old, 25 m wide, composed of oaks, hornbeams, poplars, silver firs and bushes, noise levels were 6–7 dB(A) lower than in the level grass-covered country. Without doubt, it can be concluded that the belts of trees are effective in railway noise attenuation.

## 5.3 Aircraft Noise

Aircraft and helicopters generate annoying noise in urban, suburban and natural recreational environments, which interferes with the aesthetic quality of the landscape (Raney and Cawthorn 1998). For example, the noise level measured in Grand Canyon National Park in the United States is 76 dB (A) for aircraft and 40 dB(A) for helicopters, as noted by Mace et al. (1999).

Aircraft noise is increasingly seen as a constraint on the future growth of aviation traffic. The noise generated by aircraft components is mainly produced

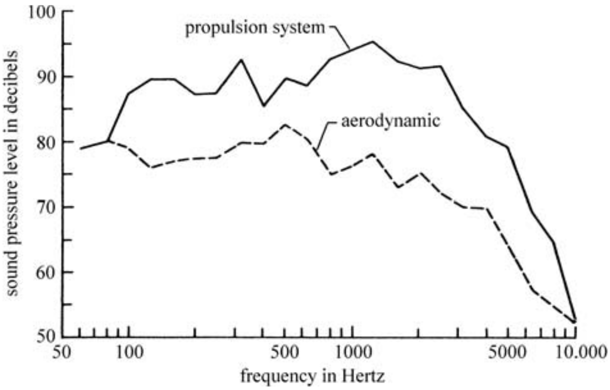


**Fig. 5.9.** Sound pressure level versus frequency for the aerodynamic noise of a turbofan aircraft compared with propulsion system noise landing approach at an altitude of 150 m and speed of about 125 knots (Raney and Cawthorn 1998). Reprinted with permission of the Acoustical Society of America, copyright 2005

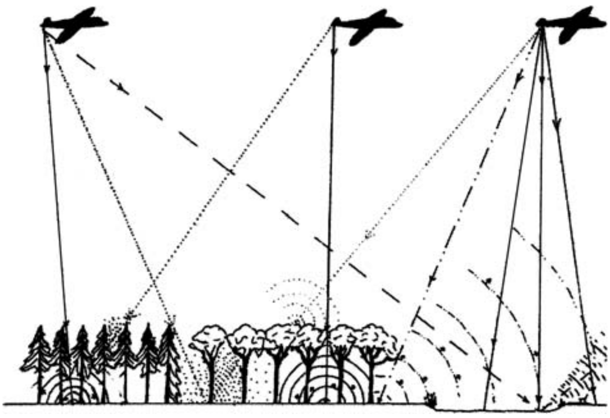

**Fig. 5.10.** Aircraft noise propagation in coniferous and deciduous forest stands (von Wendorff 1974)

by the engine's rotating blades, by the air expelled from the jet exhaust, by the airframe structure as it flies through the air, by the strong local airflow of devices and surfaces deployed during aircraft take-off or landing, etc. Figure 5.9 shows the variation in the sound pressure level versus frequency for the propulsion system and for aerodynamic noise. The maximum sound pressure level (95 dB) was observed around 1 kHz.

The mechanism of aircraft noise propagation through forest is demonstrated in Fig. 5.10, which shows the aircraft displacement in three successive positions. The noise radiated from the aircraft propagates through the atmosphere and interacts with the forest stand and the ground. Figure 5.11 proposes a qualitative model for noise propagation phenomena in a forest stand. Four typical zones inside the forest stand favorable, or not, to noise propagation were defined by von Wendorff (1974) as follows: zone A, which corresponds to free noise propagation in atmosphere; zone B, which corresponds to the canopy zone, mainly absorbing the noise; zone C, or a shadow zone in which the noise is mostly reflected; zone D, or a resonance zone situated under the canopy and acting as a wave guide. In the figure, the characteristic free space between trees noted 'a' for coniferous forest stand or 'd' for deciduous trees acts as a noise amplifier; and, for this reason, the author labeled this corresponding amplifying effect as the 'trumpet effect'.

Today's best airliners are about a factor of four quieter than the first airliner introduced more than four decades ago, but the annoyance with aircraft noise

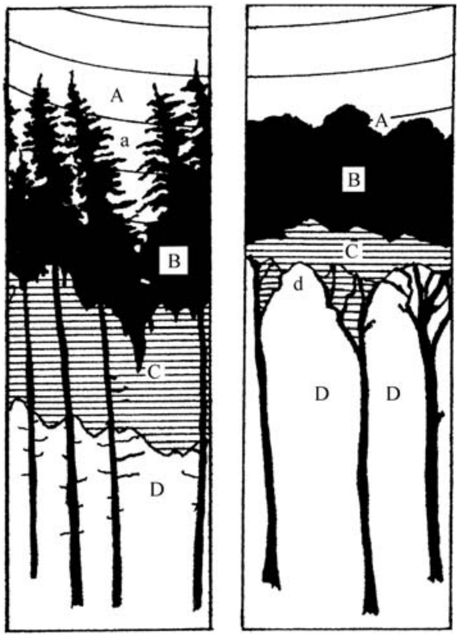


**Fig. 5.11.** Typical zones inside the forest stand favourable or not to noise propagation (von Wendorff 1974). *A* Free noise propagation in atmosphere, *B* zone of canopy, absorbing the noise, *C* shadow zone in which the noise propagation is reflected, *D* resonance zone under the canopy acting as a wave guide. The characteristic free space between the coniferous trees (*a*), or deciduous trees (*d*) acts as a noise amplifier

in recreational areas and at home is very much criticized because of increasing aircraft traffic and airport noise, since noise has been recognized as a serious environmental pollutant. An annoyance weighting factor has been proposed to express annoyance in social surveys by residential populations living near airports (von Gierke et al. 1998). People more highly annoyed at home tended to be more annoyed than others while in recreational areas (Krog and Engdahl 2004). Noise sensitivity in response to aircraft environmental noise is an independent predictor of annoyance, which statistically can explain up to 26% of the variance (van Kamp et al. 2004).

Forest stands planted near airports can be a good solution for the reduction of the noise annoyance produced by the continuous growth of aviation traffic and can contribute to the well-being of the traveling public and the communities surrounding airports.

## 5.4 Summary

Outdoors, a description of the noise environment in the audible range is provided by the A-frequency weighted day-and-night average sound level. The environmental noise impact depends on the total energy received at the observation point, the rate of occurrence of noise events and the magnitude of noisier single events. The reduction in noise level requires the following three main steps: evaluation of the noise environment under existing conditions, determination of the acceptable noise level and determination of the difference between the two previous steps. In urban communities, the sources of noise are numerous and may include noise produced by highways, rail and aircraft transportation. The techniques for noise control are related to control at the source, at the receiver and at the transmission path.

The main outdoor sources of noise in modern life are generated by traffic on streets or highways, by rail transportation and by aircraft.

Models of different complexity have been used for traffic noise prediction since 1950. A unification of noise calculation algorithms in Europe was realized with the standard ISO 9613-2 (1996). The propagation of highway noise over a forest stand expressed by the variation in sound pressure level versus distance has clearly shown the important attenuation produced by forest stands. In urban areas, trees can be used as noise buffers, able to reduce noise by 5–10 dB, if some general recommendations are respected (plant trees near the noise source, plant trees/shrubs with dense foliage as close as possible, plant belt trees of 7–17 m wide, etc.).

Rail transportation is one of the most used systems throughout the world for passengers and freight within urban and suburban areas. The noise is produced by the propulsion system of the railcars and locomotives, by the interaction between the wheels and rail and by aerodynamics-connected phenomena. Rail systems generate ground-borne vibrations which are important and depend on the resonance frequencies of the train suspension systems and the smoothness of the wheels and rails. The attenuation effect of belt vegetation is combined with the terrain configuration.

Aircraft and helicopters generate annoying noise in urban, suburban and natural recreational environments, which interferes with the aesthetic quality of the landscape. The noise radiated from the aircraft propagates through the atmosphere and interacts with the forest stand and the ground. Forest stands planted near airports can be a good solution for reducing the noise annoyance produced by the continuous growth of aviation traffic.