

# Noise reduction with porous asphalt - costs and perceived effect

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**ABSTRACT:** Three test sections of two-layer porous asphalt and a reference section of dense asphalt concrete were laid on Øster Søgade in Copenhagen in 1999. An extensive measurement program including noise, surface characteristics and traffic safety is part of the project, which also includes a before-after questionnaire survey on noise annoyance among those living along the road. Two-layer porous asphalt pavements are more expensive than ordinary dense pavements, but comparisons done as part of the project of the cost of porous asphalt, noise barriers and sound insulation shows the asphalt to be economically attractive where there is a need for reduction of the traffic noise. The questionnaire survey shows that the reduction in decibel is matched by a reduction in annoyance both in and outside the homes of those living along the road.

## 1. INTRODUCTION

The problem of road traffic noise is smaller in Denmark than in many European countries, but still 20 percent of all homes are exposed to noise levels exceeding 55 dB ( $L_{Aeq,24}$ ), which is the Danish guideline value. 6 percent are exposed to more than 65 dB, which is the level the primary national objectives for noise abatement are based on. Most of the exposed homes are in urban areas, where the selection of possible abatement measures is limited.

Some improvements can be achieved through traffic planning by concentrating the traffic on major roads, and in some cases it may be possible to build noise barriers along these roads. In general, however, barriers are not a feasible solution along urban roads. Instead sound insulation can be used to secure acceptable noise levels inside the homes, but this still leaves problems outdoors and when windows are open. On many roads the most realistic means of abatement besides or in addition to sound insulation is noise-reducing pavements.

On roads with speeds exceeding 70 km/h one-layer porous asphalt with 8 mm chippings (PA8) reduces noise by 3 dB compared with dense asphalt concrete (DAC), but at lower speeds the pores clog up whereby the noise reducing effect is lost [Bendtsen, 1996]. Two-layer porous pavements based on a concept developed in the Netherlands are presently being tested on a city street in Copenhagen with speeds of 50 km/h [Bendtsen, 1999-2]. On a pavement with a top layer of 25 mm PA8 and a bottom layer of 45 mm PA16 a 4 dB noise reduction has been achieved when the pavement was two years old. So far the results indicate that the pores can be kept open by high pressure cleaning twice a year [Bendtsen et al., 2002]. In this paper it is assumed that this is the case, and that the 4 dB noise reducing capacity is maintained throughout the lifetime of the pavement.

Noise reducing pavements should also be considered as an alternative or supplementary means of noise abatement on roads where it is possible to set up barriers. Barriers have the greatest effect at ground level, and the effect decreases with increasing height above the ground. The effect of barriers at apartment buildings is therefore limited to the lower floors, whereas reductions achieved by the use of noise reducing pavements are the same everywhere. Because the pavements are effective against tire-road noise the noise reduction is likely to be higher than 4 dB on roads with

higher speeds. It is likely that reductions of 5-6 dB can be achieved depending on the driving speed [Heerkens et al., 1998].

An important aspect in considerations on choice of abatement method is the cost of the various means. This paper will compare the cost of a two-layer porous pavement consisting of PA8/PA16 (25mm/45mm) with the costs of noise barriers and of sound insulation of building facades. As the aim of reducing noise is to reduce the annoyance felt by people, the perceived effect of the various means of mitigation is also taken into consideration.

## 2. CASES

Porous asphalt, noise barriers, and sound insulation as means of noise abatement are compared through three different hypothetical cases: a 50-km/h central city street, a 70-km/h ring road, and a 110-km/h freeway running through a suburban area. These three cases give a fair coverage of the wide span of situations where noise abatement may be necessary.

The cases are thought up and simplified in order to allow for easy calculation of noise and costs, but they give an indication of the pros and cons of the different means of abatement. All calculations are done for one kilometer of road without intersections and with the same building structure along the whole road.

The city street is a narrow but heavily trafficked shopping street of the kind that can be found in most major European cities in areas developed in the late 19<sup>th</sup> century. On both sides of the road there are closed rows of 6-story apartment buildings with shops on the ground floor. Assuming that an apartment on average has a 15 meter long facade towards the road [DEPA, 1998], the 2 times 1000 meters has room for 665 apartments, or 133 apartments on each floor.

The road is 15 meters wide including sidewalks and bicycle paths. There is one lane in each direction, the speed is 50 km/h, the annual daily traffic (ADT) is 12.000 vehicles, and there are 10 percent heavy vehicles (trucks and busses). The noise levels ( $L_{Aeq,24h}$ , free field values which is used for administrative purposes in Denmark) on the facade of the apartments are calculated using the Nordic Prediction Method for Road Traffic Noise [NCM, 1996]. With no abatement the noise levels vary from 68 dB on the 1<sup>st</sup> floor to 65 dB on the 5<sup>th</sup>.

The ring road is a four-lane road with a width of 32 m including bicycle path, sidewalk and a 5 m wide verge on each side of the road. Along both sides of the road are 3-story apartment blocks parallel to the road. Again 15 m long facades are realistic, and with 133 apartments on each floor there are 399 apartments along the road. The speed is 70 km/h and ADT is 30.000 with 10 percent heavy vehicles. The noise levels on the facades are 73-74 dB with no abatement.

The freeway runs through an urban area, and it is therefore realistic that the road profile is narrow. The 3 lanes in each direction are separated by a 2 m wide median strip. On each side there is a 3 m shoulder and a 5 m verge before the gardens of the first row of houses start. The first row of houses is 10 m further from the road. The distance between the rows of houses is 25-30 meters. Half of the houses are 1-story, the other half are 2-story. Assuming that there is a house for every 23 m of road [DEPA, 1998], there are 87 houses (44 2-story and 43 1-story) in each row if both sides of the road are added together.

The speed is 110 km/h, ADT is 60.000, and there are 10 percent heavy vehicles. The noise levels on the facades of the houses are 77 dB on both floors in the first row, 69 dB on the ground floor and 71 dB on the first floor of the 2<sup>nd</sup> row, and 66 dB and 69 dB respectively at the 3<sup>rd</sup> row. Calculations of noise levels above the height of 2 meters at houses, which are partly screened from the road by another row of houses, is beyond the validity of the Nordic Prediction Method. These results for the first floor are therefore subject to some uncertainty.

### 3. NOISE REDUCTIONS

Porous asphalt, barriers and insulation result in different levels of reduction. On top of this asphalt and barriers reduce noise both inside and outside people's homes, whereas insulation only reduces levels inside, and only if windows are kept closed. This makes it difficult to compare not only the effect of the means of abatement, but also the economy in using them.

To get around this problem comparisons in reduced decibel have been supplemented by comparisons based on the Danish Noise Exposure Factor (NEF) [RD, 1989]. NEF is an expression for the accumulated noise annoyance in a housing area. The more NEF can be reduced the more the annoyance is reduced. Based on noise levels in 5 dB intervals the noise exposure factor weighs noise based on the annoyance (Table 1) and on the situation. In this context the relevant weighing according to situations is indoors (0.6), outside windows (0.2), and on primary outdoor areas (0.2). On the city street and the ring road there are no outdoor areas towards the road, so this factor is left out in these two cases. As an example Table 2 shows calculations for the freeway with no abatement. The number of houses at each noise level in an area is multiplied by the annoyance factor for the noise level, and the products are added up. This sum is multiplied by the relevant situation factor for outside windows, outdoor areas or indoors to produce the NEF-value for the specific situation. The NEF-values for the three situations are then added together to produce the overall noise exposure factor. With outdoor levels below 55 dB and indoor levels below 30 dB the NEF-value is 0.

Table 1. Annoyance factors in the Danish Noise Exposure Factor (NEF).

$L_{Aeq,24}$		30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80
Factor	In	.11	.22	.45	.93	1.92	3.94				
	Out						.11	.22	.45	.93	1.92

Table 2. Example of calculation of NEF based on the freeway with no noise abatement.

$L_{out.win.}$	Annoy. factor	No. of houses	$L_{out.areas}$	Annoy. factor	No. of houses	$L_{in}$	Annoy. factor	No. of houses
75-80	1.92	87	75-80	1.92	87	50-55	1.92	87
70-75	.93	44	70-75	.93		45-50	.93	
65-70	.45	174	65-70	.45	174	40-45	.45	174
60-65	.22	44	60-65	.22		35-40	.22	88
55-60	.11	86	55-60	.11	174	30-35	.11	86
Situation factor		0.2	Situation factor		0.2	Situation factor		0.6
NEF <sub>outside windows</sub>		61.1	NEF <sub>outdoor areas</sub>		52.9	NEF <sub>indoors</sub>		164.5
Noise Exposure Factor			278.5					

On the city street only porous asphalt and sound insulation are considered, as there is no room for a noise barrier. At 50 km/h a noise reduction of 4 dB from the porous pavement is realistic [Bendtsen et al., 2002]. Sound insulation with 6-12-4-9-4 (6 mm glass, 12 mm space, 4 mm glass, 9 mm space and 4 mm glass) isolated glass windows reduces the noise by 9 dB compared with ordinary 4-12-4 windows, which are used for comparison. With ordinary windows the difference between indoor and outdoor noise levels is typically 26 dB [Bendtsen et al., 2002]. Table 3 shows the NEF-results.

On the ring road it is possible to put up a barrier, so here all three alternatives are considered. The porous pavement is considered to reduce the noise level by 5 dB, and insulation reduces it by 9 dB. A 2.5 m high barrier located on the verge right next to the sidewalk reduces the noise level on the facade of the building by 12 dB on the ground floor of the apartment building but has no effect on the 1<sup>st</sup> and 2<sup>nd</sup> floor. 2.5 m is considered a realistic height on this kind of urban road.

On the freeway all three means of abatement are relevant. The effect of the insulation is 9 dB, the pavement reduces noise by 6 dB, and a 3 m high barrier results in a 13 dB reduction on the ground floor of the first row of houses and 6 dB on the 1<sup>st</sup> floor. More could be achieved with a higher barrier, but a higher barrier would also cast longer shadows into people's gardens. Noise

levels and NEF have only been calculated for the first 5 rows of houses from the road even though the noise levels on the 1<sup>st</sup> floor of the 2-story houses in the 5<sup>th</sup> row are very high (65 dB).

Table 3. NEF-values for all combinations of noise abatement on the three 1000 m long road sections.

	Without abatement	Means of abatement						
		Barrier	Insulat.	Barrier + Insula.	Asphalt	Asphalt + Barri.	Asphalt + Insula.	All 3
City str.	202.7	–	103.7	–	117.0	–	29.3	–
Ring r.	296.9	221.3	126.9	90.4	143.6	107.5	62.2	44.4
Freeway	278.5	83.2	154.8	39.8	99.0	21.1	61.1	9.6

#### 4. COSTS

The costs (in Euros) of the various means of noise abatement are compared as net present value (NPV) for a 30-year period. 25-30 years is according to the Danish Road Directorate the expected lifetime for barriers and insulation [Bendtsen et al., 2002]. The bottom layer of the two-layer porous asphalt has an expected lifetime of 15 years, and the top layer has to be renewed after 7-8 years [Bendtsen, 1999-1].

The calculations of NPV is done without taking benefits into consideration, thus using the formula

$$NPV = \sum_0^{29} \frac{C_t}{(1+r)^t} \quad (1)$$

where  $t$  is a year,  $C_t$  is the cost in the year  $t$ , and  $r$  is the calculation rent. The calculation rent is set to 7 percent, which is the rent usually used for Danish infrastructure projects.

When laying porous asphalt on urban roads it will – in order to maintain the height of the curbstones - often be necessary to rebuild the road completely because the porous asphalt layer is much thicker than an ordinary layer of dense asphalt concrete. However, many urban roads in Denmark are old and have not been built for today's traffic load, so often the major roads will need a rebuild anyway. When calculating the costs of porous asphalt it is therefore reasonable to only take into account the difference in costs as compared with a road paved with dense asphalt concrete.

The top layer of 25 mm PA8 costs €5.4 per m<sup>2</sup>, the 45 mm PA16 bottom layer costs €9.7 per m<sup>2</sup>, and 30 mm of DAC (the alternative to porous asphalt) costs €5.6 per m<sup>2</sup>. The load capacity of the 70 mm thick porous pavement is higher than that of a 30 mm DAC pavement, so the foundation for a road with PA8/PA16 can be 30 mm thinner than for one with DAC. This saves €4.7 per m<sup>2</sup> [Bendtsen et al., 2002].

When the top layer of the porous pavement or the entire porous or the DAC pavement has to be renewed, the cost for removing the old pavement is €3.4 per m<sup>2</sup> [Bendtsen et al., 2002]. When using porous pavements on urban roads it is necessary to install drainage pipes on the two sides of the road. The cost of pipes and installation is estimated to be €3.6 per m [Bendtsen et al., 2002]. This cost is excluded on the freeway, where there are no curbstones, and therefore no need for pipes.

To keep the pores of the pavement open on low speed roads the pavement has to be high pressure cleaned regularly at an estimated price of €0.07 per m<sup>2</sup> per cleaning. On the city street this is done twice a year and on the ring road once a year. At the same time the drainage pipes should be cleaned at an estimated price of €1.34 per m.

Winter maintenance of porous asphalt is estimated to cost 50 percent more than maintenance of DAC, because salt is drained away and therefore must be spread more often. The Danish Road Directorate has variable annual expenses of €3,220 per km for winter maintenance [Bendtsen et al., 2002]. On porous asphalt the expense is expected to be €4,830 per km.

Including all building and maintenance costs for porous asphalt and subtracting those for DAC the cost (NPV) of using PA on 1000 meters of road over a 30-year period is €296,000 on the city street, €360,000 on the ring road, and €477,000 on the freeway.

The cost of sound insulation is on average €4,030 for apartments and €6,640 for houses [Bendtsen et al., 2002]. Maintenance costs are not considered, as they are assumed to be the same for ordinary windows and noise reducing windows. Noise reducing windows are likely to save energy for heating, but this benefit is disregarded in this context. For the 665 apartments on the city street the cost of insulation amounts to €2,685,000. Along the ring road it is €1,607,000 for the 399 apartments, and for the freeway it is €578,000 for each row of 87 houses (both sides of the road). For the five rows included in these calculations it amounts to €2,890,000.

A 2.5 meter high high-quality noise barrier costs €255 per m<sup>2</sup> and a 3 meter high one costs €242 per m<sup>2</sup> [Bendtsen et al., 2002]. Maintenance costs are approximately €2.2 per m per year. Building and maintenance costs amount to €1,335,000 on the ring road and €1,590,000 on the freeway for a 1000-meter long barrier on each side of the road. The abatement costs are shown in Table 4 and Figure 1.

Table 4. Costs (net present value) and effect of the 3 means of noise abatement. The cost/dB/dwelling is based on linear averages of the noise reductions inside the apartments or homes.

		City street	Ring road	Freeway
Asphalt	30 year cost	€296,000	€360,000	€477,000
	dB reduction	4	5	6
	NEF reduction	85.7	153.2	179.4
	Cost/dB/dwelling	€11	€80	€83
	Cost/NEF	€3,454	€2,350	€2,659
Barrier	30 year cost	–	€1,335,000	€1,590,000
	dB reduction	–	0–12 (average: 3.9)	0–13 (average: 6.2)
	NEF reduction	–	75.5	195.3
	Cost/dB/dwelling	–	€858	€590
	Cost/NEF	–	€7,682	€8,141
Insulation	30 year cost	€2,685,000	€1,607,000	€2,890,000
	dB reduction	9	9	9
	NEF reduction	99.0	170.0	123.7
	Cost/dB/dwelling	€449	€448	€738
	Cost/NEF	€7,121	€9,453	€23,363

In these examples porous asphalt is clearly an effective means of noise abatement as it both regarding straightforward reductions in decibel and reductions in NEF is very cost effective (Figures 2 and 3). The reductions in dB are not as great as those achieved with barriers or insulation, but the effect is on the output level from the road and thus works everywhere along the road, whereas barriers and especially insulation are limited in the receiving positions for which they work.

As it can be seen in Table 3, the noise levels in all three cases are so high that no combination of asphalt, barriers, and insulation can completely solve the problems, understood as securing noise levels lower than 55 dB outside and 30 dB inside the dwellings. (These indoor and outdoor noise levels would result in a NEF-value of 0.) This implies that the question is not necessarily which means of abatement to choose, but rather which combinations of means are necessary to achieve acceptable noise levels. The cases used for exemplification in this paper involve fairly high noise levels, but even in less severe cases it will often be necessary to use more than one means of abatement to obtain acceptable noise levels.

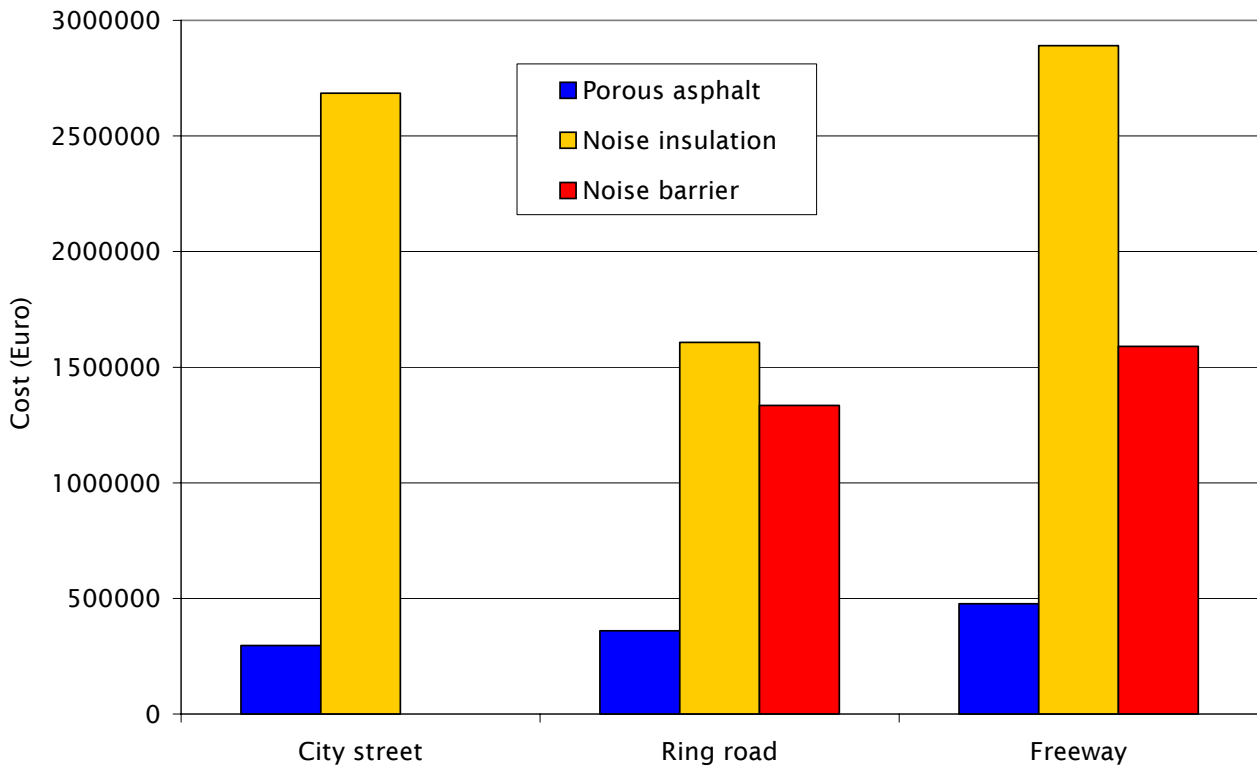


Figure 1. The costs of porous asphalt, noise insulation and noise barriers in the three cases.

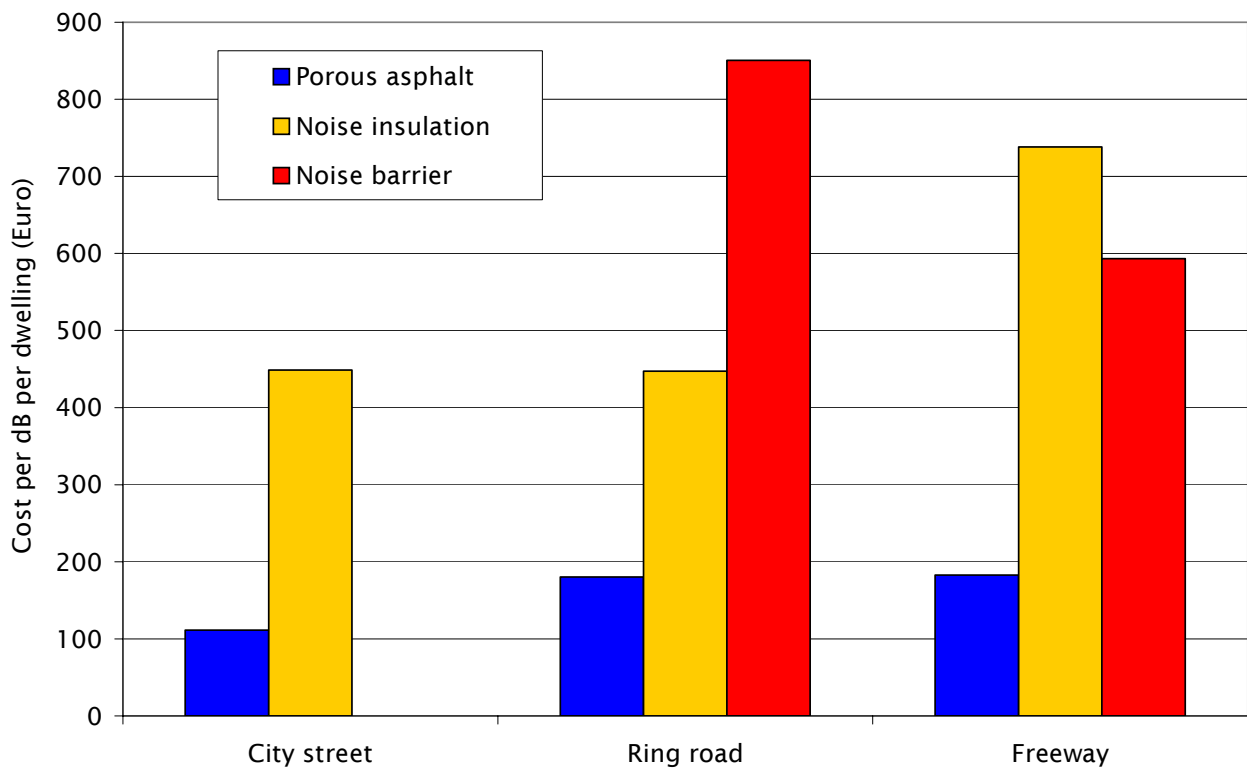


Figure 2. Cost per dB per dwelling for porous asphalt, noise insulation and noise barriers for each of the three cases.

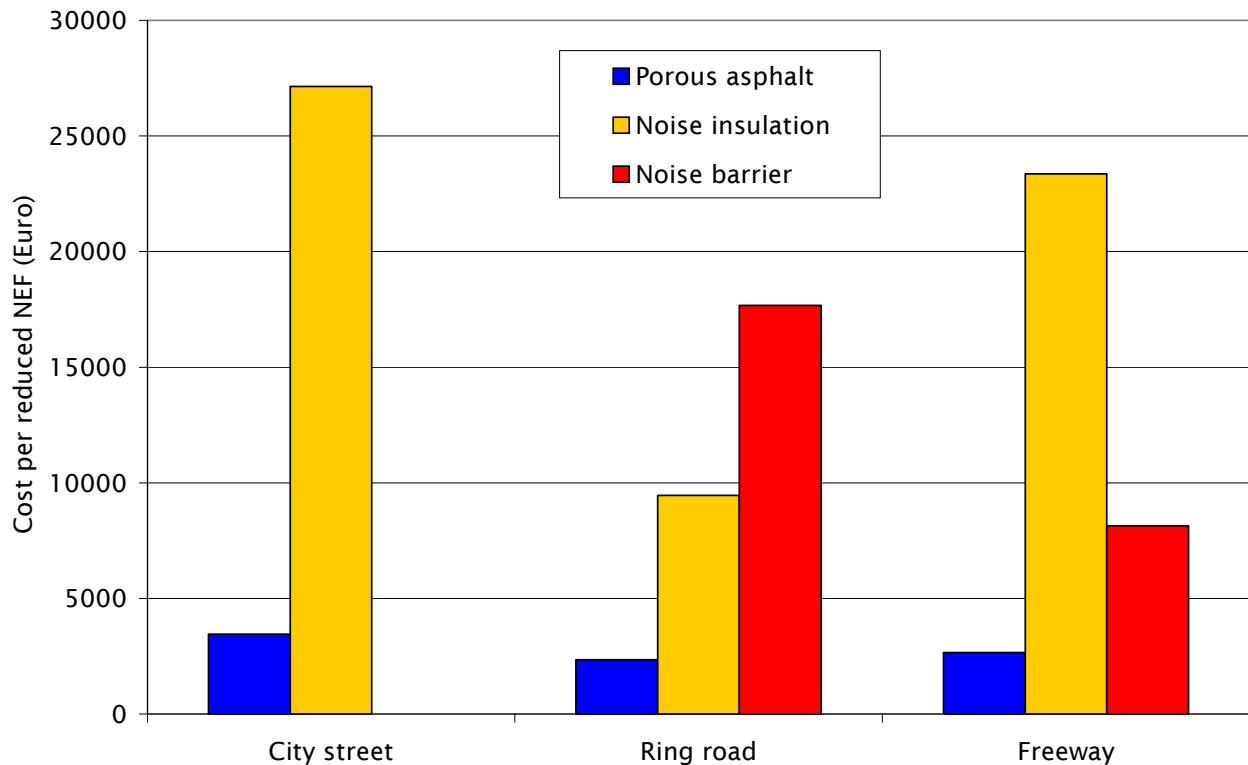


Figure 3. Cost per reduced NEF for porous asphalt, noise insulation and noise barriers for each of the three cases.

## 5. PERCEIVED EFFECT

A questionnaire survey on perceived noise annoyance has been conducted among the people living in the apartments and houses along Øster Søgade. Before the rebuilding there was an old worn out pavement with stone loss, holes and cracks where the noise was measured to a level 2-3 dB higher than the new reference pavement. The before-after questionnaire survey on Øster Søgade shows significant reductions in the annoyance of those living along the road (Figure 4 and 5). Both at the reference section and along the test sections the annoyance has decreased, which is not surprising as the noise levels decrease both places compared with the before-situation. The decrease in both noise and annoyance was however much greater along the test sections than along the DAC reference section [Bendtsen et al., 2002; Larsen & Bendtsen, 2001].

Figure 6 shows the percentages respondents who state to be a little or more annoyed compared with a dose-response relationship from a large Danish survey on noise annoyance [Bendtsen et al., 2000]. Before the repaving of Øster Søgade the percentage annoyed is much higher than would be expected from the dose-response relationship. It also appears that the reductions in noise annoyance among those living along the sections with porous asphalt, and to some extent also along the reference section, is somewhat larger than would be expected from the reductions in noise levels. However, it is a fairly small survey, so the results should be viewed with some caution. Also, the Øster Søgade survey is done as a before and after survey, whereas the dose-response relationship is based on a single survey. It is likely that the improvement in noise conditions causes a greater shift in annoyance than would be expected from surveys based on statements from persons subjected to unchanging conditions.

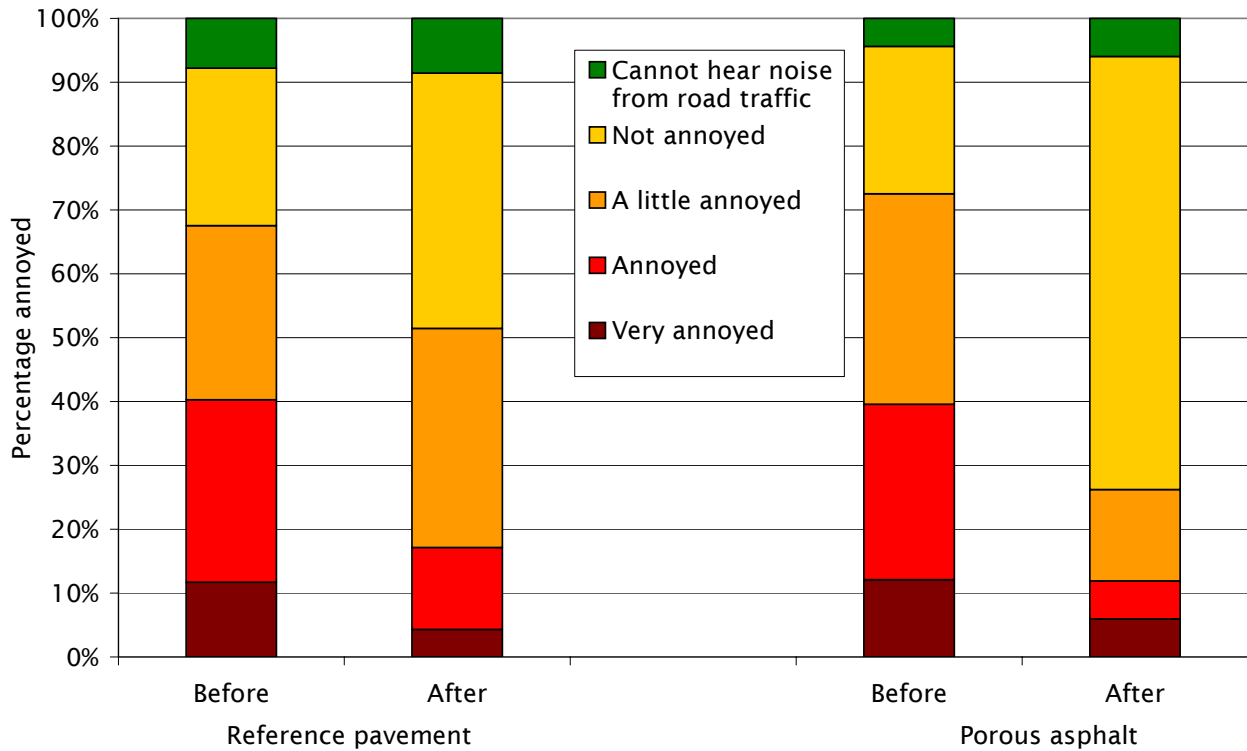


Figure 4. Annoyance at noise from road traffic indoors with closed windows before and after Øster Søgade was paved with noise reducing porous asphalt [Bendtsen et al., 2002].

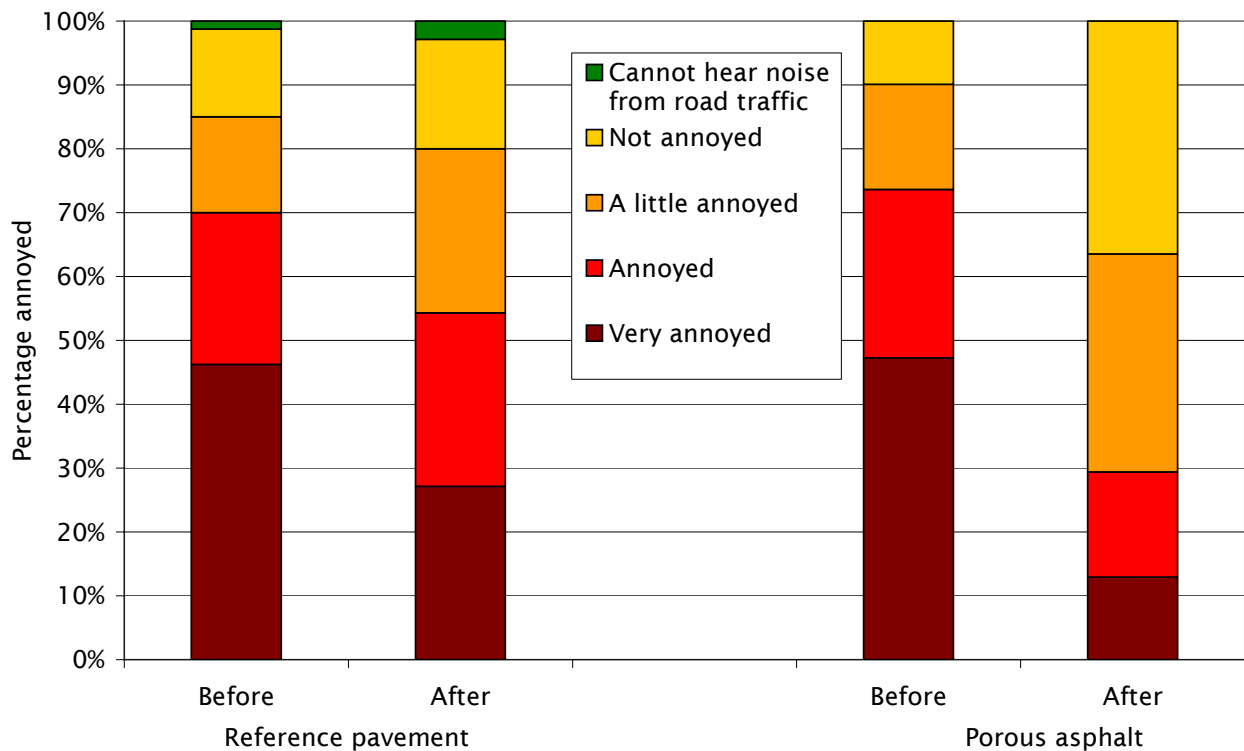


Figure 5. Annoyance at noise from road traffic indoors with open windows before and after Øster Søgade was paved with noise reducing porous asphalt [Bendtsen et al., 2002].

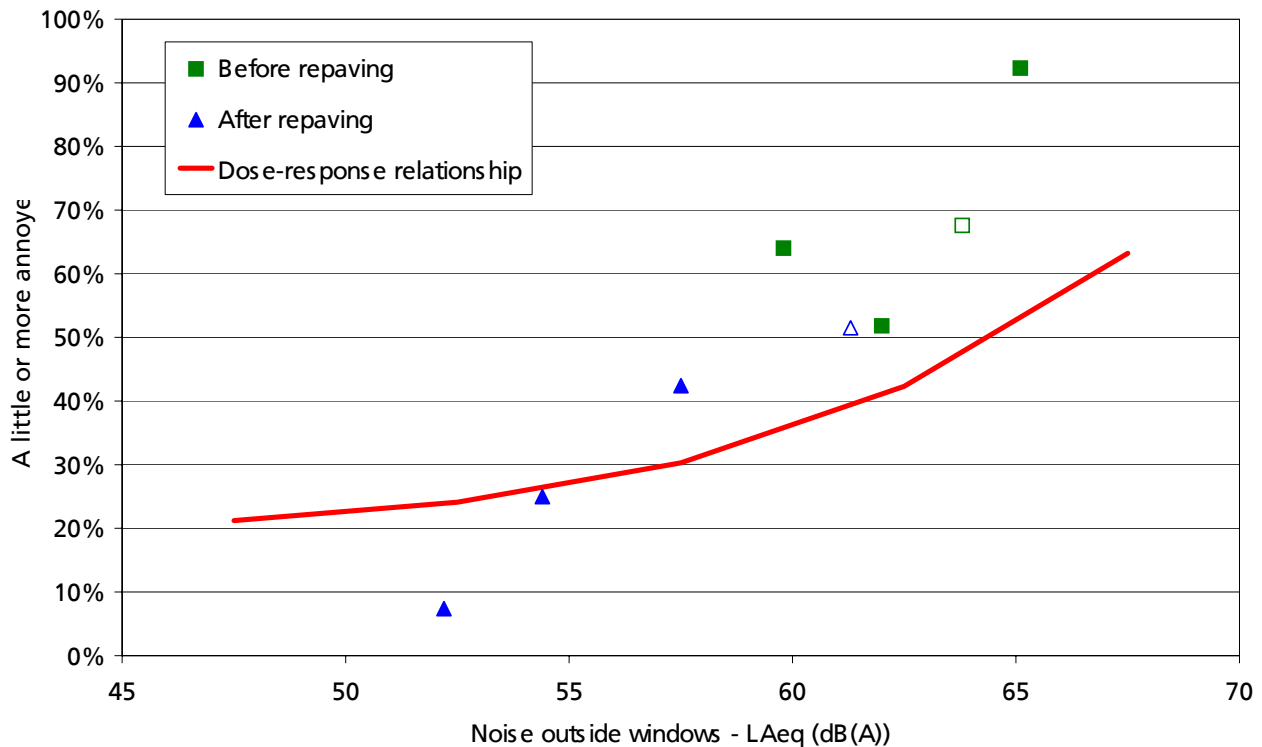


Figure 6. Annoyance at noise from road traffic indoors with closed windows before and after Øster Søgade was paved with noise reducing porous asphalt. The filled in markings are from the sections with porous asphalt and the outlined markings are from the reference section. The dose-response relationship for ‘a little or more annoyed’ is from a large Danish survey on annoyance from road traffic [Bendtsen et al., 2000].

A pilot study on noise barriers [Bendtsen & Larsen, 2001-1 and 2] does not show nearly as positive reactions to the effect of the barriers as the Øster Søgade survey shows to that of the pavement. Questionnaire surveys among residents in three different areas, which had recently received noise screens, show that although there is a majority of persons experiencing a decrease in the noise levels, between 7 and 24 percent state that the noise levels have increased. The screens reduced noise by between 5 and 16 dB. The experience of increasing noise levels may be due to disappointed expectations as to the effect of the barriers, but it could also be because the barriers cause other nuisances (visual intrusion, blocking people’s way, casting shade in gardens) which the pavement does not.

## 6. CONCLUSIONS

Two-layer porous asphalt is in Denmark still in a phase of testing and development as a means of noise abatement. The test sections on Øster Søgade will be monitored in the years to come, and further projects testing porous asphalt are under consideration. It is therefore still too early for firm conclusions as to the effects and applicability of porous pavements. The results presented in this paper do however indicate that porous asphalt is likely to be an effective and economically attractive alternative or supplement to the well-established means of noise barriers and sound insulation. This is under the assumption that the noise reduction can be maintained during the whole lifetime of the pavement.

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