Analysis of Outdoor Noise Level in the Residential Area, Herlevhuse

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Preface

This report is the outcome of a project on a special course in environmental acoustics at the Technical University of Denmark undergone in January 2015. The investigation of the study is initiated on request by the residents association of Herlevhuse.

The report is conducted by Lærke Philipsen and Lasse Hamborg, students at the Architectural Engineering Master's programme at DTU.BYG under supervision of Associate Professor Cheol-Ho Jeong.

We would like to acknowledge the guidance and lending of software that Brüel & Kjær, and especially Douglas Manvell, has put forward for the project.

In addition, we would like to acknowledge the traffic data that we have received by ViaTrafik and Metroselskabet.

Last but not least, a thank should fall onto the residents of Herlevhuse in their cooperation with the measurements and questionnaires. Especially thanks to chairman Karin Larsen with her crucial help on distribution and collection of the questionnaires and initial guidance on the problem.

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1 Introduction

Herlevhuse is a residential area in eastern Herlev, Zealand, a suburb to Copenhagen. It is limited by Langdyssen, Runddyssen, Meteorvej and Ametystvej and it includes the 264 properties enclosed by the red line in Figure 1. As seen in Figure 2, the residential area is located near Herlev Hospital (a regional hospital with large capacity), Ring Road O3 and Highway E47.

The residents association has called upon an investigation of the noise level in the area due to complains and vacating from the area. This project is conducted in cooperation between the Technical University of Denmark (DTU) and the residents association of Herlevhuse (HH) in order to conduct such an investigation as part of a special course at DTU.

Figure 1: Aerial view of the 264 properties of Herlevhuse. O3 is seen in the bottom left. SOURCE: GOOGLE EARTH

1.1 Scope of investigation

The scope of this project is solely to investigate the noise level in the area. The project will not be drawing any conclusions towards political decisions i.e. the need for noise barriers or financial compensation.

The project will try to conduct the noise investigation through questionnaires, measurements and simulations based on calculations of basic data.

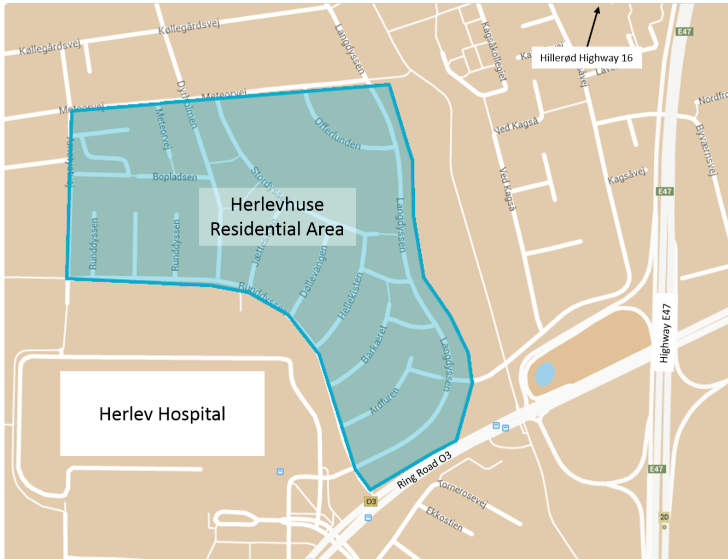


Figure 2: Placement of Herlevhuse and nearby infrastructure.
SOURCE: GOOGLE MAPS

Whilst doing so, the project will provide background theory about road noise and certain key thresholds.

2 Background

In this section, the background theory of the study is outlined. Terms that lay the foundation for noise analyses are explained followed by theory from the literature about road noise.

2.1 Noise from roads

The term 'noise' is used for sounds in our presence that is perceived as unwanted in the context of the receiver (the person(s) whom are exposed to the noise). The term 'environmental noise' is thus used for noise from sources in the surroundings of the environment, e.g. aeroplanes, industrial factories, weather conditions or traffic. Noise is just as regular sound measured in dB. However, the dB level of noise is always A-weighted due to the sound perception of the human. Thus, one rarely notates dB(A) but solely dB (Vejdirektoratet 2010b).

Traffic is usually the cause of the most noise pollution as it occurs almost everywhere. Vehicles on roads emit noise when they are driving due to the engine running and the contact between rubber tiers and the ground. When the traffic is increasing, the spaces between the cars are decreased, thus the noise becomes more continuously and floats into a regular stream of noise. The same thing happens the further away from the source (the road/traffic) the receiver gets.

In general, the noise is decreased 3 dB for every time the distance to the source is doubled. Although, Vejdirektoratet (2010a) states that the terrain surface decreases the noise level more significantly than the distance. A soft terrain surface thus decreases the noise level with 6 dB in a doubled distance and a hard surface 4 dB.

Regarding noise from traffic, it is obvious that the quantity and the speed of the traffic has an impact on the noise level.

The quantity can in some matters be changed, but even by rather big changes as a decrease of 50 % of the vehicles, will only contribute to a noise level decrease of 3 dB as Table 1 on the following page shows.

The driven speed of the traffic also has an affect on the noise level. Table 2 shows that the biggest change in the noise level can be achieved between 40 and 90 km/h. The decreases in noise levels in Table 2 can be added up due bigger jumps. E.g. a decrease in driving speed from 90 to 50 km/h will

Table 1: Examples of noise dampening levels due to decreasing of traffic quantity.

Noise dampening	**Removed traffic**
1 dB	25 %
3 dB	50 %
5 dB	65 %
10 dB	90 %
20 dB	99 %

SOURCE: VEJDIREKTORATET (2010A)

Table 2: Affect of speed decrease on noise level. Changes can be added up.

Change in speed	**Decrease in noise**
From 130 to 120 km/h	0.9 dB
From 120 to 110 km/h	0.9 dB
From 110 to 100 km/h	0.9 dB
From 100 to 90 km/h	0.9 dB
From 90 to 80 km/h	1.3 dB
From 80 to 70 km/h	1.4 dB
From 70 to 60 km/h	1.4 dB
From 60 to 50 km/h	1.5 dB
From 50 to 40 km/h	1.2 dB
From 40 to 30 km/h	0.7 dB

SOURCE: VEJDIREKTORATET (2010A)

result in a noise level decrease of 5.6 dB.

When vehicles are driving above 50 km/h, it is the wheels rolling on the ground that is the main source for the noise. Below 50 km/h, another 0.5-1 dB can be won by reducing the number of heavy vehicles. Considering the roads in the area, it should be noted that the speed limit for O3 is 70 km/h. On E47, the limit is 110 km/h and in all other smaller roads, it is 50 km/h.

Regarding the 'quality' of the noise, Vejdirektoratet (2010a) states that uneven noise is perceived more annoying than continuous noise. This happens when the noise picture is interrupted by e.g. big trucks or ambulances. Here, it shall be noted, that the investigated residential area, HH, is located right besides Herlev Hospital.

It should however be noted, that for the present situation of HH, the number of vehicles are not likely to change, as O3 and E47 are important infrastructural roads. The driving speed on O3 is currently 70 km/t but during rush hour, a lot of queue is formed, limiting the speed significantly. Although, this creates a more uneven noise pattern with a lot of accelerations.

2.2 Scale for noise, L_{den}

According to Vejdirektoratet (2010b), a clear connection between the average value of the noise and the nuisance of the noise-exposed neighbours has been shown. Therefore, the noise is usually calculated or measured as an average value. The commonly European used scale for noise average is L_{den}, measured in dB(A). It is an average scale that takes into account that noise exposure is more crucial in the evening and in the night-time. Hence, the 'den' stands for day-evening-night. It does so by adding 5 dB and 10 dB respectively to the noise levels of the evening and the night-time. According to Vejdirektoratet (2010b), the periods are defined as:

- Daytime: 07 – 19 (12 hours)
- Evening: 19 – 22 (3 hours)
- Night: 22 – 07 (9 hours)

The L_{den} value is thus an average of the very noise level throughout the whole day calculated via the Formula 1 that weights the evening and night noise level with 5 and 10 dB respectively.

$$L_{den} = 10 \cdot \log \left(12 \cdot 10^{\frac{L_{Aeq,d}}{10}} + 3 \cdot 10^{\frac{L_{Aeq,e}+5dB}{10}} + 9 \cdot 10^{\frac{L_{Aeq,n}+10dB}{10}} \right) \tag{1}$$

2.3 Noise exposure

Exposure to noise can be a stress factor for residents living nearby the source if it is constantly ongoing. Stress can lead to high blood pressure and on a long-term scale premature death. In Denmark, it is estimated that up to 2200 people every year are hospitalised due to noise (Vejdirektoratet 2010a).

The Danish Ministry of the Environment has presented some guiding thresholds for road traffic noise which are used to evaluate if an areas is exposed to noise. In a residential area and in outdoor living areas, the guiding threshold for noise is $L_{den} > 58$ dB. At this value, 15 % of the population will feel highly annoyed by noise. Above this limit, the area is considered noise congested. If the noise in the area exceeds 68 dB, the area is considered heavily noise congested (Vejdirektoratet 2010a).

As the threshold is set to the top 15 % fractile, this will be reused in the analysis of the questionnaires. The threshold of 58 dB will be used in analysis of the simulation and the measurements.

2.3.1 Jurisdictions on road noise

When establishing new residential areas nearby new or existing roads, the guiding thresholds of the Danish Ministry of the Environment applies. When planning new roads, the ministry recommend that the same thresholds are used, although this is not a demand

Even if/when the thresholds are exceeded, Vejdirektoratet (2010a) reveals that neither the Environment law nor the Planning law allows for intervening the noise problems at existing residents from existing roads.

2.4 Noise map

When possessing knowledge of different aspects of the road, i.e. the geometry, the number of vehicles, types of vehicles, geometry of the residential area, etc., a noise map can be generated. A noise map shows the noise level L_{den} at 1.5 m above the ground. It is a general picture of the noise in the area throughout the whole year. That is due to the data used for calculating the noise map.

The noise map is used to calculate and determine the noise level over an area, usually including residences as receivers. The noise map is useful as it quickly can be assessed where there is noise congestion in general and also what can be done about it. With the noise map, one can quickly calculate alternative situations, e.g. with or without noise barriers.

The Danish Ministry of the Environment provides a noise map of the whole of Denmark online[1]. In this model, all main roads and also rail roads and bigger industrial areas of Denmark are modelled and the traffic noise in any

[1] `http://noise.mst.dk`

area can be found. It is built from a model, Nord2000, which is a Nordic developed model from 2007. Its features and properties are well explained in Vejdirektoratet (2010b).

2.4.1 Noise map of HH

Looking at the noise map of HH in Figure 3[2], it is seen that almost all of the area is exposed to noise of 55 dB (yellow) and that one third of the area is noise congested with more than 60 dB noise (orange and up). Many of residences near the O3 is exposed to loud noise of up to 70 dB and in a few cases up to 75 dB. These residences can therefore be considered heavily noise congested according to the noise map and Vejdirektoratet (2010a).

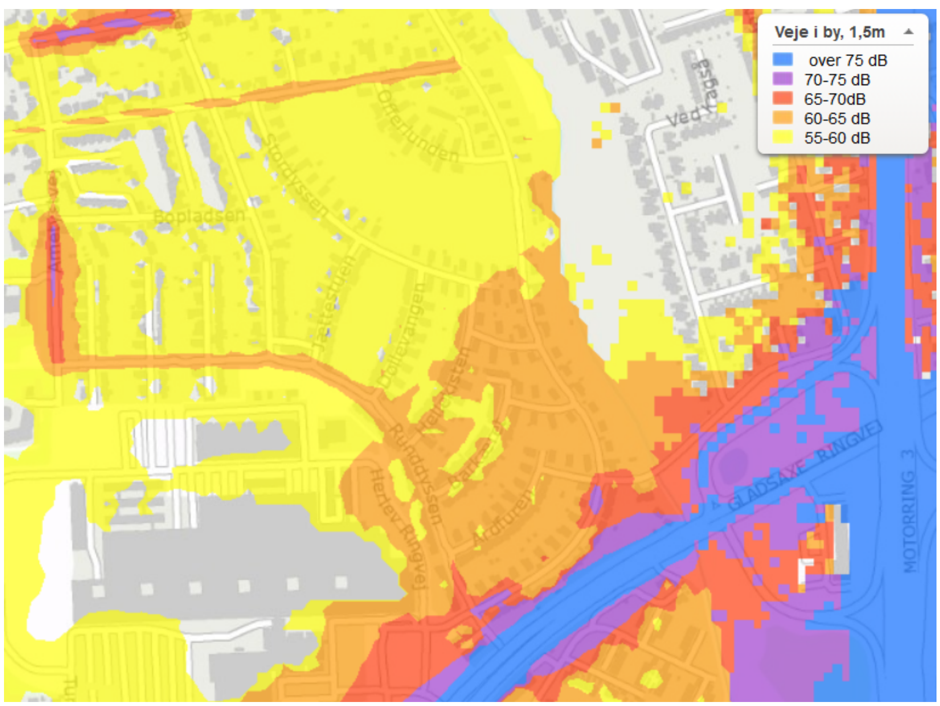


Figure 3: Noise map of HH with noise from city roads in 1.5 m height.
SOURCE: DANISH MINISTRY OF THE ENVIRONMENT

[2]Direct link to noise map of the area: `http://miljoegis.mim.dk/spatialmap?selectorgroups=themecontainer%20vejstoj&mapext=714967.2%206181395.4824951%20717426.4%206182400.2824951&layers=theme-gst-dtkskaerm_daempet%20theme-pg-noisedataarea-b1&mapheight=625&mapwidth=1541&profile=noise`

2.5 Measurements of noise

Vejdirektoratet (2010a) states that measurements of noise only can be used as a random sample result for the specific spot and time. It cannot give a general picture of the area nearby or the very same place in another time scale.

Measurements can though be good to assess the reality in a receiver spot. Measurements can for instance reveal if the noise problem is accumulated mostly in the night-time or in the daytime.

3 Method

This project investigates the noise propagation in the area of HH through three different approaches:

1. Questionnaires answered by the residents in the area.
2. Measurements of sound level on 3 different spots in the area.
3. Simulations based on the amount of traffic on O3 and E47.

Combining and comparing the data from these three methods will result in valid results.

3.1 Questionnaires

To assess the problem among the residents, questionnaires was distributed. The questionnaire contains three qualitative questions regarding the residents' perception of the noise level; one qualitative question and a query regarding an agreement on noise measurements being conducted in the residents' garden:

1. On a scale from 1-5, how bothered are you by noise in your residential area?
2. When during the day do you feel mostly bothered by noise? (1-5)
3. Where do you think the noise is mostly coming from? (1-5)
4. What is your general perception of the noise propagation of Herlevhuse?
5. Can we measure the noise level in your garden?

In question 2, six time spans of four hours each were to be rated from 1-5:

- 00:00 - 07:00
- 07:00 - 12:00
- 12:00 - 15:00
- 15:00 - 19:00

- 19:00 - 22:00
- 22:00 - 00:00

In question 3, seven noise source opportunities were presented:

- Neighbours
- Industry/Hospital
- Big roads
  - Ring Road O3
  - Hillerød Highway 16
  - Highway E47
- Smaller roads
- Other? (Write)

The questionnaires were distributed to all 264 residences – one per property.

3.2 Measurements

As mentioned in Section 2.5 on page 11, measurements of noise levels can give a good picture of the actual situation in the spot of measurement, while it cannot generate a full picture of the area in total.

The measurements are to support the determination of an L_{den} value. Thus, the measurements are to be done in the daytime, evening-time and night-time as explained in 2.2.

The time scale for each measurement follows:

- **Day:** 90 minutes
- **Evening:** 50 minutes
- **Night:** 20 minutes

The noise level is measured at a height of 1.5 m above the ground according to the noise map.

Figure 4: Location of the three measuring spots.

During the measurements, the traffic on O3 is to be counted to estimate the traffic level at time of the measurements. Heavy vehicles (trucks, lorries and busses) were counted separately. This specific road is chosen due to the questionnaires pointing to this road as the most noise polluting source in the area.

As of the unique location close to the hospital, ambulances occur more often than usual on this road as it is the only in and out of the hospital for the ambulance. The occurrence of ambulances with sirens on is thus counted too.

The measurements was conducted the 13^{th} of January The weather conditions were noted due to their influence on the measurements.

3.2.1 Locations

According to the outcome of the questionnaires and investigation of the noise map in Figure 3, three spots were chosen for conduction of measurements of the noise level in the garden. Two spots near the O3 and a spot further up in the area. The spots are marked on Figure 4 and were the following:

1. Langdyssen 10
2. Langdyssen 26
3. Stordyssen 22

(a) Set-up on tripod. (b) Pointed towards source.

Figure 5: Sound level meter set-up

3.2.2 Equipment

Two sound level meters from Brüel & Kjær, type 2250 were used for the measurements. They were set up to measure 1/3 octave band. All measurements were conducted with windscreen on. The meters were attached to tripods in a height of 1.5 meters and pointed towards the noise source as seen in Figure 5.

Counting of vehicles on O3 were done manually without equipment.

3.3 Simulation

Two simulations were made in this analysis. Both have geometry and conditions in a way that they corresponds as much as possible to the situation of the measurements conducted the 13^{th} of January 2015. The only difference between the two simulations were the adding of a noise barrier with the same parameters as the E47 barriers in the second simulation.

Simulations of noise can be done by many different software platforms. In this project, the software Predictor, developed by Brüel & Kjær, were used. This software predicts the sound propagation in an area based on geometry and source information. In this case, the sound sources are O3 and E47. The sound is based on the amount of light and heavy vehicles on the two roads in the three day time periods. These two roads are not the only sources of noise in the area. It is known from the questionnaire that noise from the hospital, traffic from the smaller roads in the area and neighbours are sources of noise too. The focus in this report, however, is to analyse how much the noise from the bigger roads are propagated in the area, and these other sources are therefore neglected. Due to these different sources not being considered, the overall sound level pressure will be higher than the simulated results.

3.3.1 Geometry

To make the map, geometry is imported to Predictor. This includes roads, buildings and terrain lines. Since E47 has sound barriers, this has to be imported or applied as well. In this project, the TOP10DK database is used. TOP10DK is a collection of different kinds of geographical data in Denmark. This is for example points of archaeological sites, windmills and telecommunication masts; lines of rivers, roads and terrain and lastly polygons of buildings, lakes and administrative areas (such as municipalities). In TOP10DK, the data is given for the whole of Denmark. It is perfectly possible to import the roads and height lines, since the line data is quite simple. In Predictor, these are defined as 'roads', which is a noise source layer, and height lines, which instantly define the shape of the terrain. To embody the ground, a 'ground region' is drawn.

The building data is harder to import. The layer of data includes all buildings in Denmark and thus requires huge computer power to import. Since this analysis is concentrated in a quite small area, it is possible to draw the buildings based on an orthophoto.[3] The houses in HH are type houses, and they are easily copied. Besides HH, Herlev Hospital and a couple of buildings on the other side of O3 are drawn. The geometry of Herlev Hospital is important since it has large geometries and lies between HH and O3, and the buildings on the other side of O3 will reflect noise from the road.

[3] An aerial photograph geometrically corrected ("orthorectified") so that the scale is uniform

When E47 was expanded, Claus Bjarrum Arkitekter was the architect team behind it. The solution is a highway with a simple and elegant noise barrier, which is customised for the residents in the near of the highway. As a standard, the barrier is made of aluminium screens with a top of glass, which allows the light to shine through it so the houses next to it would not stand in shadow. In some cases, the light from the cars annoyed the residents, and a taller aluminium screen then replaced the glass panel (Vejdirektoratet 2008).

The barrier itself, which can be seen in Figure 6, is 3 to 4 meters high with a slope of 10 degrees towards the road. The barrier is made as a perforated panel absorber[4] with a lot of small holes and stone wool in the core of it. On the outside of the barrier, racks are added to enable climbing plants to cover the new, unwanted surface.

In the simulation the barriers are added as a 4 m high, vertical noise barrier with the predefined reflection factors of 0.8 for all frequencies.

3.3.2 Road data

To calculate the noise effect from the two roads, data about the amount of light and heavy vehicles has to be found. The traffic counting company ViaTrafik has counted traffic in the area to support the construction of the new Ring 3 Tram Line, conducted by Metroselskabet (the metro company). These numbers are compared to the traffic counted during the measurements in the area and the counted numbers are imported to Predictor. The numbers from ViaTrafik are counted in the two rush hour periods, i.e. 07:00-10:00 and 15:00-18:00. Due to the need of traffic data for evening and night, the data counted during the measurements are used. The amount of traffic on the sections of O3 to the west and east are also added. Here, only the ViaTrafik numbers are available. The percentage of vehicles in the evening and night periods, compared to day, is found from the counted numbers and applied to the data from ViaTrafik.

Regarding the E47 highway, the number per annual daily traffic is found to be 98 600 thousands vehicles.[5] As this simulation evaluates the weekday

[4] Lecture given by Cheol-Ho Jeong, Fall 2014, DTU, 31241 Building Acoustics

[5] `http://www.vejdirektoratet.dk/DA/viden_og_data/statistik/trafikken%20i%20tal/hvor_meget_trafik_er_der_paa_vejen/Trafikstr%C3%B8mskort/Documents/2013%20aadt/Kort18.pdf`

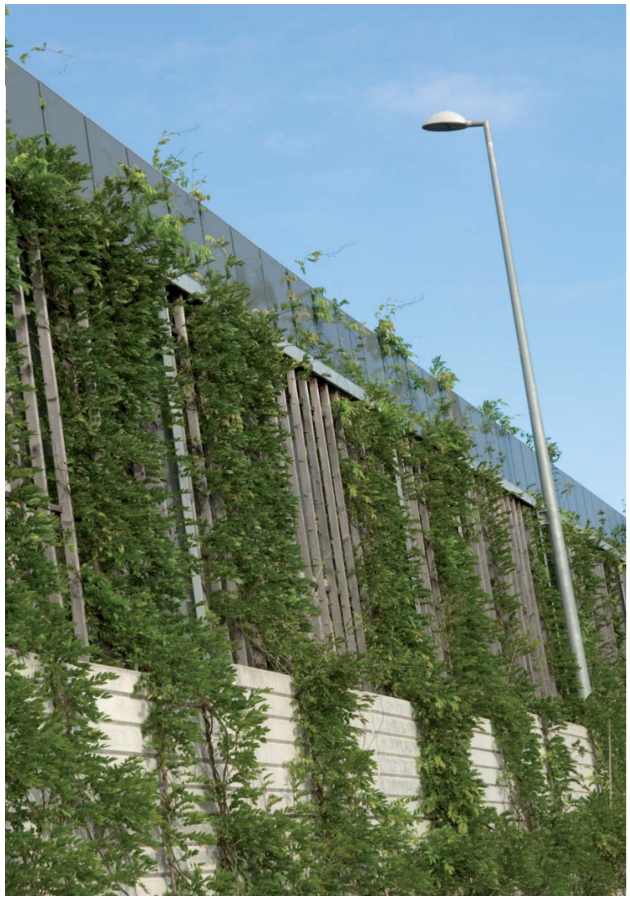


Figure 6: Noise barrier on the E47 highway.
SOURCE: VEJDIREKTORATET

traffic, this adds up to 108 460 vehicles per annual weekday traffic (when multiplying with 1.1(Anderson 2014).

It is calculated that 83 % of all traffic in the area takes place during the 12 daytime hours (07:00-19:00), 6 % during the 3 evening hours (19:00-22:00) and 10 % during the 9 night hours (22:00-07:00). This is applied to the total of 108 460 vehicles and distributed evenly on the hours of the periods, which is shown in Table 3. It is assumed that the traffic is divided evenly on southbound and northbound of the highway. Lastly 5 percent of the traffic is assumed to be heavy vehicles.

Table 3: Vehicles on E47 per hour after applying percentages.

Period	**Vehicles/hour**
Day	7545
Evening	2266
Night	1235

3.3.3 Noise model

At the noise map for Denmark, the noise model Nord2000 is used. This model is meanwhile not available in Predictor. Instead, the open source model Harmonoise is used. The two models have a lot in common since they both implement both geometry, road data and more importantly weather data, which not all models include. The situation for this analysis is road noise on a winter day, and since the standard is in summer, the weather data is very important to include. The factors in the Harmonoise model consist of:

- Geometry on ground, buildings and roads.
- Road data on number, kind and speed of vehicles driving on the source roads, separated in the tree day time categories.
- Surface data on the ground and how sound absorbing it is.
- Weather data on wind direction and speed class as well as air temperature, humidity and pressure.

Nord2000 and Harmonoise use the same factors but the approaches in the models are different. Jónsson and Jacobsen (2008) states that Harmonoise and Nord2000 uses the same approach handling spherical divergence, air absorption and energy losses during refection. Meanwhile, the effects of ground reflection, diffraction from barriers and scattering zones are handled differently and the simulation of refraction and turbulence in the meteorological conditions (e.g. vertical temperature, wind profiles and atmospheric instability) is handled very differently.

From this, Harmonoise is considered comparable with Nord2000 and thereby the noise map.

3.3.4 Grid and receivers

Last thing to add before running the calculations is the calculation grid and receiver points. The grid is added to the whole area with a density of a point every 50 meters in both X and Y direction. Furthermore, a more dense mesh is added from O3 and approximately 300 m in the north-west direction, around the E47 highway and its belonging exit road. Lastly, three receiver points are added at the same spots as where the measurements were conducted. The entire model can be seen in Figure 7.

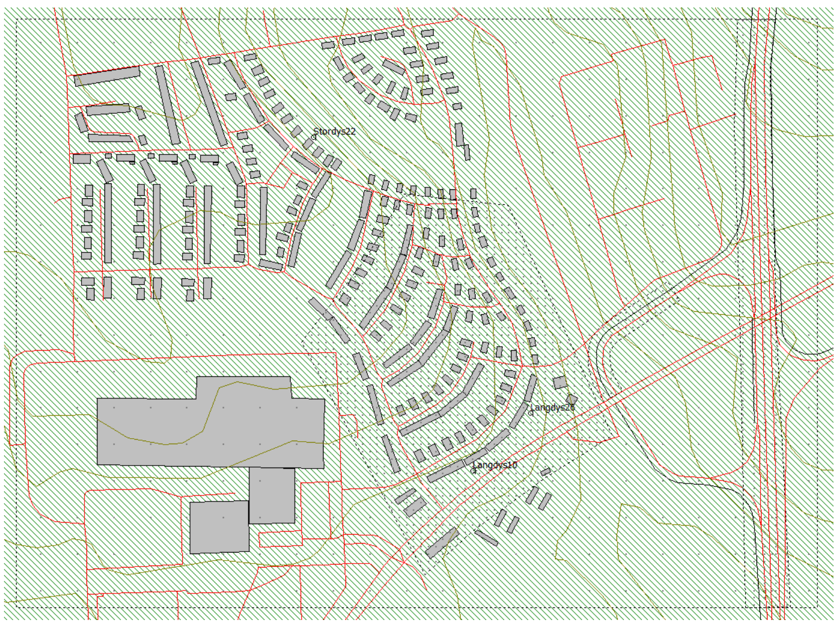


Figure 7: Final model for the noise simulation of the noise in the residential area.

4 Results

This section will present the results from the three investigations: Questionnaire, simulation and measurements.

4.1 Questionnaire

Out of 264 residences, 99 answered the questionnaire. Out of these, 38 were complete with an answer to all four questions. 13 were returned with a comment only. The quantity of answers of the remaining questions were as follows:

1. 46 answered
2. 76 answered
3. 81 answered
4. 84 answered (commented)

34 residents answered Question 2 but not Question 1. In total, 80 residents answered either question 1 or 2. An average assessment of the noise in the area is derived from these entries.

Question 1 - Annoyance

The 46 answers to question 1 distributes as shown in Table 4.

The top 15 % percentile is 4. 48 % of the answers were a score 4 or 5 ('annoyed' or 'very annoyed').

Question 2 - Time of the day

The scores of the 76 answers to Question 2 is summed up in Table 5. The average score for each time slot is shown in the table. The answer quantity is the number of residents that put a score to the time slots. The distribution of the scores for each time slot is showed in Table 6. In the bottom of the table, the top 15 % fractile is showed according to the literature.

Table 4: Quantitative distribution of assessments of Question 1.

Value	**1**	**2**	**3**	**4**	**5**
Answers	6	11	7	15	7
Average				*3.13*	

Table 5: Summed assessment score per time slot in Question 2. Total score: 895.

Time slot	**00-07**	**07-12**	**12-15**	**15-19**	**19-22**	**22-00**
Assessment score	100	197	148	241	132	77
Answer quantity	45	58	47	65	47	37
Average score	2.2	3.4	3.1	3.7	2.8	2.1

Table 6: Distribution of assessment scores in each time slot.

Score	**00-07**	**07-12**	**12-15**	**15-19**	**19-22**	**22-00**
1	25	11	9	9	10	20
2	5	8	6	8	12	5
3	4	8	12	6	10	5
4	2	9	9	12	7	3
5	9	22	11	30	8	4
Top 15 % fractile	3	4	3	4	3	3

Over 15 % rated the time slots 07:00-12:00 and 15:00-19:00 with a score of 4 or 5. In the total score, these two time slots combined scored 49 % of the total score.

For those residents whom had not answered Question 1, an average of the scores in Question 2 was derived and joined with the poll of answers in Question 1. The distribution of the residents, whom this includes, is showed on Figure 8. The color index refers to the average assessment score.

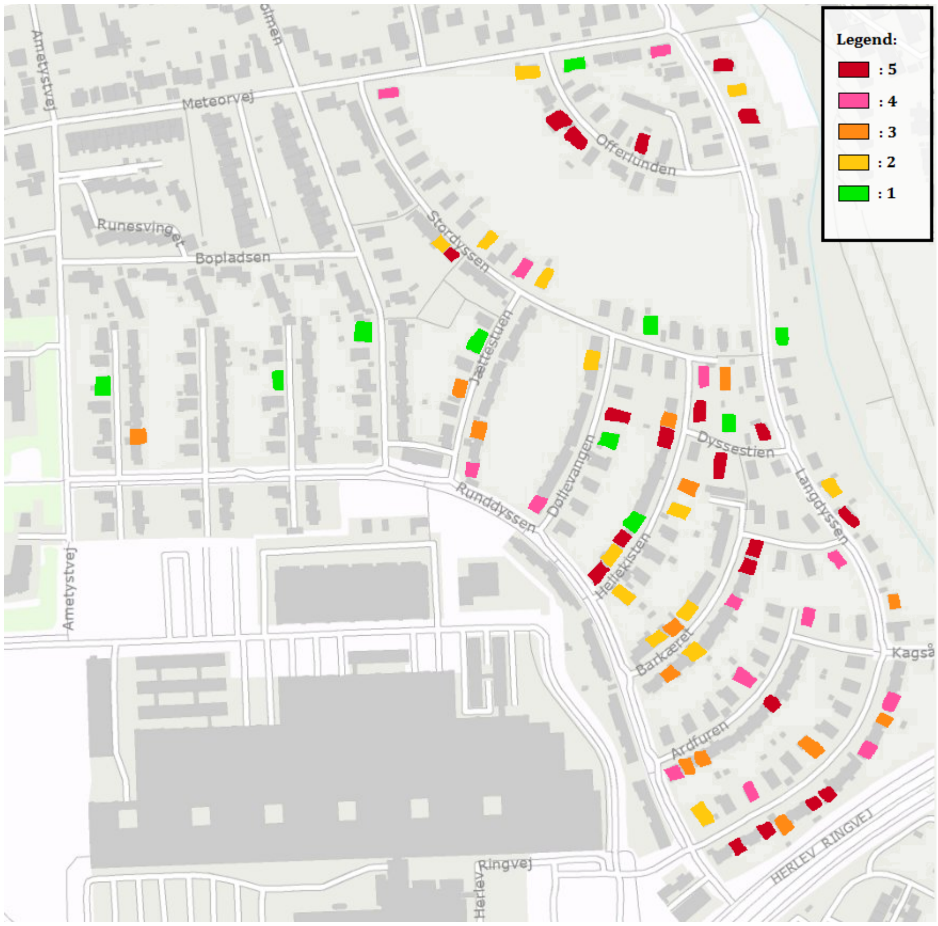


Figure 8: Map of residences that rated the noise level in Question 2. The color index refers to the average noise level score.

Question 3 - Noise source

In Question 3 regarding the residents' perception of the noise source, the scores for the various sources are distributed as showed in Table **??**. The total score for the noise sources are showed in Table **??**.

Question 4 - General perception

The 4^{th} question is qualitative and contains comments from the residents. 84 answered Question 4.

The comments address different kinds of problems regarding the noise in the area. The following are the most common topics:

- 10 comments mention the noise from ambulances.
- 8 comments mention the hospital in another context (i.e. the construction site of the present expansion, the ventilation system or various traffics on the hospital).
- 11 comments mention the wind direction as having an influence on the noise level.
- 6 comments mention that the noise is worst during rush hour in the morning and in the afternoon.

4.2 Measurements

The measurements were conducted in three different locations as shown in Figure 4 on page 14. The noise level L_{Aeq} is measured and the bypassing traffic at O3 is counted during each measurement.

The results of the measurements of the noise level L_{Aeq} and the calculated L_{den} value for the three locations in the three periods are shown in Table 7 on the following page. The spot numbers refers to the locations explained in 3.2.1 on page 14.

The counting of the bypassing traffic is showed in Table 8 on the following page.

4.3 Simulation

Two simulations were made. One with the geometries and conditions of the measure time, seen in Figure 9 on page 26, and one with an added sound barrier between O3 and HH seen in Figure 10 on page 26.

Furthermore the three receiver points had results calculated for the three periods. These are shown in Table 9 on page 27 and 10 on page 27.

Table 7: Results of the measurements of the noise level L_{Aeq} in three locations in HH.

	Day		**Evening**		**Night**		$\boldsymbol{L_{den}}$
	Time	$L_{Aeq,d}$ *[dB]*	*Time*	$L_{Aeq,e}$ *[dB]*	*Time*	$L_{Aeq,n}$ *[dB]*	*[dB]*
Spot 1	15:10	64.2	20:55	58.8	22:33	57.6	65.8
Spot 2	15:15	57.5	20:00	59.8	23:05	57.4	64.3
Spot 3	17:03	45.0	18:59	42.6	22:00	67.0[1]	72.7[1]

[1] Extra measurement showed a noise level of $L_{Aeq,n} = 40.6$ dB. This adds up to an $L_{den} = 48.2$ dB.

Table 8: Results of the traffic counting at O3.

	Period		**Eastbound**		**Westbbound**		**Sirens**
	Time	*Duration*	*Light*	*Heavy*	*Light*	*Heavy*	Total
Day	15:40	20 min	630	17	580	14	5
	17:26	20 min	383	6	290	5	2
Evening	19:22	20 min	159	3	161	3	0
	20:05	20 min	152	1	130	3	1
	21:00	20 min	117	2	101	2	1
Night	22:02	10 min	39	0	41	1	0
	22:30	10 min	25	1	45	1	0
	23:00	10 min	30	1	37	2	1

Figure 9: Simulation of the noise propagation from O3 and E47.

Figure 10: Simulation of the noise propagation from O3 and E47 with noise barrier along O3.

Table 9: Simulation results in receiver points.

Address	L_{day} **[dB]**	$L_{evening}$ **[dB]**	L_{night} **[dB]**	L_{den} **[dB]**
Spot 1	60.6	55.7	54.0	62.1
Spot 2	59.7	54.6	52.9	61.0
Spot 3	32.6	27.3	24.8	33.5

Table 10: Simulation results in receiver points in simulation with noise barrier.

Address	L_{day} **[dB]**	$L_{evening}$ **[dB]**	L_{night} **[dB]**	L_{den} **[dB]**
Spot 1	49.1	44.0	42.2	50.5
Spot 2	49.2	44.0	42.1	50.4
Spot 3	32.6	27.3	24.8	33.5

5 Analysis

5.1 Questionnaire

The questionnaires revealed that 48 % of the residents are bothered by the noise level in their residences and rated the noise level with a score of 4 or 5 ('annoyed' or 'very annoyed') in Table 4 on page 22.

During the day, the time slots during rush hour (07:00-12:00 and 15:00-19:00) are the most noise polluting ones. Several commentaries point this out specifically. In total, 15 % of the residents has rated the rush hour time slots with a score of 4 or 5. Therefore, these must be considered as noise congesting periods.

Out of seven potential sources, 26 % of the residents rated the O3 to be the most noise polluting source and was rated with an average score of 3.6. The E47 highway was also rated high with a score on 3.6.

5.1.1 Location

Evaluating the noise perception of the residents in relation to their location, illustrated in Figure 8 on page 23, a clear tendency can be seen: The closer to O3 the occupants are living, the more bothered by noise they are.

Comparing the noise map in Figure 3 on page 10 with Figure 8 (residents whom had assessed the noise level in the questionnaire), several observations appear:

1: It is seen that the roads Runddyssen, Hellekisten and Langdyssen form an area of which 90 % is noise congested more than 60 dB according to the noise map. Hence, this area is in the following referred to as the noise congested area. It is limited by the purple line in Figure 11. This area constitutes more than a third of the total residential area. Meanwhile, almost 2/3 (45 of 73) of the returned questionnaires derive from this area. Hence, a tendency, revealing that residents are more likely to return the questionnaires if they feel bothered by noise, is shown.

2: Within the noise congested area, only 3 of the 45 residents do not feel bothered by noise at all. Almost 50 % of the residents in this area feel bothered by noise (rated the noise level with a score of 4 or 5).

3: Considering the two roads closest to the O3, Ardfuren and the first part of Langdyssen (no. 1 through 36), only 1 of 18 residents has not rated the noise level with a high score of 4 of 5. It is also seen in the noise map that the even numbered residences of Langdyssen (those located on the right side of the road with backyard towards O3 – even numbers 2-36) almost all are located in a heavily noise congested area with more than 65 dB noise. In Figure 11, this area is located below the dark purple line.

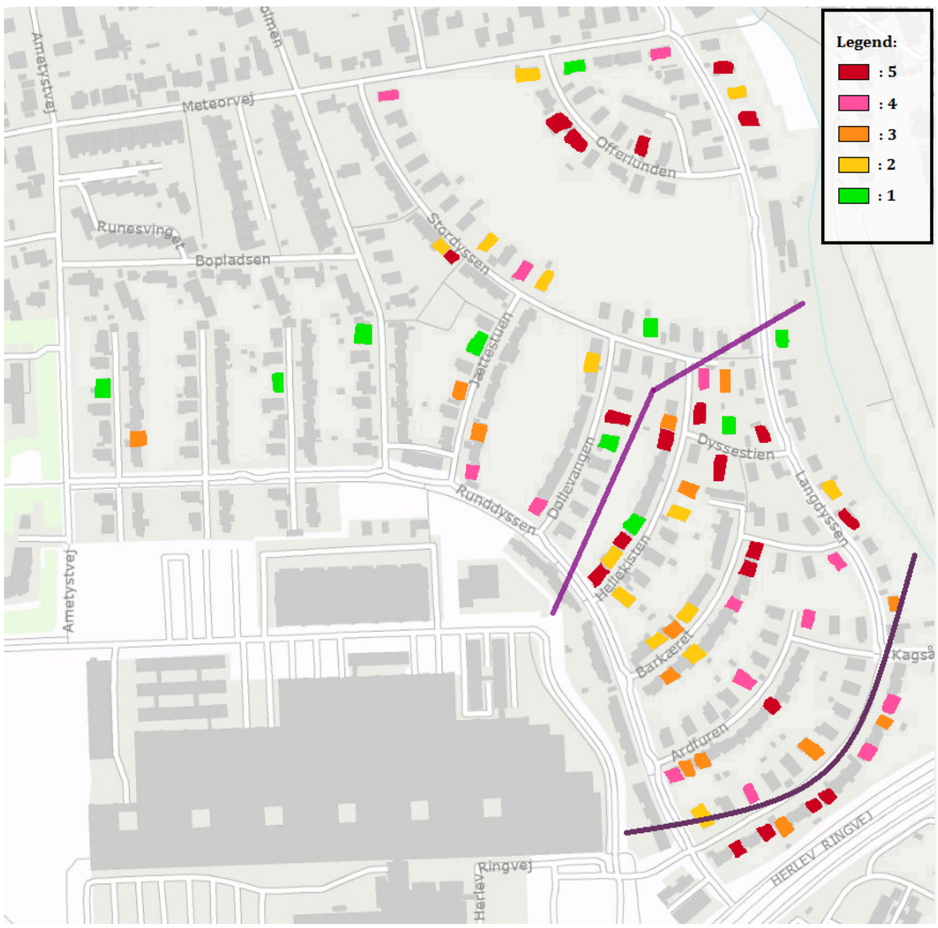


Figure 11: Residences' rated the noise level. The purple line indicates the boundary for the noise congested area to the right. The dark purple line indicates the boundary for the heavily noise congested area below.

5.1.2 Discussion of questionnaire quality

Evaluating the quality of the answers in the returned questionnaires, it is seen that more than 60 % of the questionnaires were returned with incomplete answers. Going into detail of the answers, it can be noted that the rating of the noise sources and the time periods appeared difficult and many residents just put in X's in stead of ratings. It can therefore be derived that a better quality of the survey might be preferred.

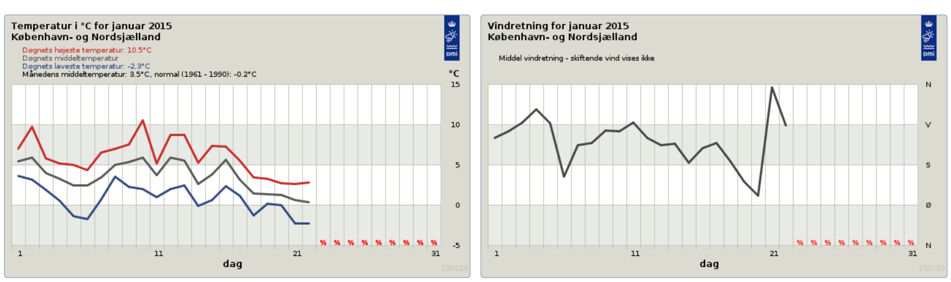
5.2 Measurements

All of the L_{den} values calculated through the measurements fits very well to the noise map in Figure 3 on page 10. However, for the L_{den} measured at Spot 3, this conclusion can only be drawn when using the 1 minute long backup measurement for the night time on 40.6 dB in stead of the 20 minute measurement on 67 dB which must be seen as unrealistically high, the circumstances taken into account.

As of these measurements, the spots 1 and 2 fall into the limit of being considered noise congested according to Vejdirektoratet (2010a) with $L_{den} >$ 58 dB. However, measurements can not lead to a conclusion as it is too time, weather and location specific.

5.2.1 Conditions

At the conduction of the measurements the 13^{th} of Januray, the temperature was around 5 °C . It had rained but dried up during the afternoon. The wind blew with steady 5 m/s from a southwestern direction. Furthermore the air humidity was 90 % and the air pressure was 1000 hPa. All of these factors affect the results of the measurements and simulation.



(a) Temperatures (b) Wind directions

Figure 12: Weather data in Copenhagen and Northern Zealand in January 2015
SOURCE: WWW.DMI.DK/VEJR/ARKIVER/VEJRARKIV/

Had the wind blown from east, the noise from the road would have been greater as some comments from the survey also mention. However, the wind comes from west or west-south-west 30 % of the time in Denmark, thus it is actually a quite realistic picture of the whole year (Cappelen and Jørgensen 1999). The wind can however affect the measurements directly as it blows onto the microphone of the equipment.

The wet roads during the daytime also increases the noise from the tiers rolling on the asphalt.

The fact that it is winter, cold and had a tendency to be rainy can also affect the noise level through the amount of people who chooses car over bicycle.

All of these parameters should be kept in mind when assessing these measurements, as measurements should be obtained during summertime. The measurements can however support the conducted simulation of the noise level as this is simulated for the present conditions of the measurements.

5.3 Simulation

The simulations can be seen in Figure 9 and 10 on page 26. When comparing them to the noise map provided by The Danish Ministry of the Environment in Figure 3 on page 10, a tendency shows in the area near O3. Both of them are based on traffic as the only source. Although in the simulation, fewer of the roads were applied traffic, i.e. only the big roads O3 and E47. The two maps have the big roads as the primary source of noise with more than 70 dB in the closest area around the roads. The big difference between the maps lies in the distribution of noise on a level lower than 65 dB. On the noise map the level is up to 65 dB in the area all the way up to Hellekisten, whereas in the simulation, this distribution only includes the first row of houses on Langdyssen. This big difference probably happens because the traffic on the smaller roads were neglected in the simulation. Furthermore the geometries probably is quite different since the geometry in the simulation is based on approximated rectangles extracted 3 meters.

It can be concluded from both maps, that the noise level is significantly high in the first row of houses. Furthermore the noise map shows a higher noise level in the southern part of HH. It seems like the first row of houses on Langdyssen shields off the noise more in the simulation than it should. Another conclusion to draw is that the noise barrier along E47 works. It clearly shields the noise so that the noise level is under 65 dB just next to the highway.

Technically, a strange propagation can be seen on O3, where blue formations are placed along the road. This is because of the coarse grid where the grid points are the sources of calculations and the noise decreases with the distance from the point. Other irregular formations have the same explanation.

Comparing the results in the receiver points in 9 on page 27 with the measurement in 7 on page 25 the tendency is that the measured results are higher than the calculated results. In Spot 1 the measured L_{den} is 65.8 dB while the calculated L_{den} is 62.1 dB. In Spot 2 the measured L_{den} is 64.3 dB and the calculated L_{den} 61.0 dB. For Spot 3 the measured L_{den} was 72.7, but as mentioned this result is not trusted, and the short 1 minute measure of 40.6, which lead to an L_{den} of 48.2 dB was much more trustworthy. It is noted that all three spots had a bigger measured than calculated value. This is perfectly normal, since a lot of sources were left out in the simulation. When considering that fact, the results looks very accurate.

5.4 Traffic

During the measurements, the bypassing vehicles was counted to get traffic data for the simulations, making the measured L_{den} values more comparable to the simulation. However, the traffic at that specific time might not have been representative for the whole day or the whole year.

The measurements took place between 15:00 and 00:00. This includes all the 3 periods of the L_{den} definition. However, the period 15:00-19:00 are usually much more dense in traffic than e.g. 10:00-14:00 due to rush hour. Additionally is the period 22:00-00:00 much less dense in traffic than the end of the night period at e.g. 06:00-07:00 also due to rush hour. This is also one of the reasons why measurements cannot conclude a noise congestion of an area.

The traffic counted on site might therefore very well be overestimated during the daytime. It can however be noted from Table 8 on page 25 that during the daytime, the Eastbound road of the O3 has over 100 more road users than the Westbound road. This might ironically enough but very well be due to rush hour, as the rush hour traffic causes lower speeds and formation of queue on the Westbound road which reduces the amount of cars per hour. The rush hour might in that matter actually reduce the noise level as the speed is lower and there is a max to how many cars that can drive through per hour without queue formation. As mentioned in Table 2 on page 7, a reduction from e.g. 70 to 30 km/h can cause a noise reduction of 4.8 dB. However, a queue of traffic just spreads the noise out to a longer period. Another problem about rush hour is also that accelerations and decelerations of the cars occur every time the light intersection changes, and that causes more uneven noise which is more annoying.

5.4.1 Ambulances

It should be noticed, that the location of the hospital near HH causes an extra amount of traffic from ambulances to and from the hospital. The noise from these ambulances is very loud due to its affect of outshouting the other traffic. These occurrences must under normal conditions be seen as a general uncertainty. However, when HH is located so close to the ambulance source, the generic calculations of the noise map might not be efficient enough as they do not include this noise source.

The traffic counting during the measurements also revealed ambulance activity in a matter that might be considered unusually high. As seen in Table 8 on page 25, a total of 10 ambulances drove by during the time of counting which sums up to 2 hours and 10 minutes. It is clear, that during the daytime, the ambulance traffic is heaviest. In 40 minutes, 7 occurrences of ambulances was recorded, while during the evening time, only 2 ambulances in one hour occurred.

The comments left in the survey also points towards this abnormal behaviour of the ambulance traffic. One comment stated the sirens of the ambulances as a great issue:

> "*The siren from the ambulance does that when we sit on the porch, we cannot talk when they drive by.*"

It should however be mentioned that the sirens of the ambulances in all cases during the traffic counting are turned off when arriving to the hospital or first turned on when entering the public intersection.

5.5 Summary

Comparing the three different investigations a clear pattern is seen. The southern area of HH is exposed to a high noise level. This is both based on expression from the residents themselves, from the measurements that showed an L_{den} of 64.3 dB and 65.8 dB at Spot 1 and 2 and from the simulation. On the other hand the investigation also showed that the northern area of Herlevhuse is not affected by the noise. This is as well supported by both questionnaires, measurements and simulations.

These two points states the suggestion of concentrating the improvements on the southern part of the area. Because O3 is a infrastructural artery, it is not a possible solution to decrease the amount of traffic or speed limit. Three concrete solutions to control the noise issues are 1) improving the acoustic insulation of the exposed residences, 2) add sound damping asphalt to the specific road or/and 3) create a noise barrier in between the source and the receiver. In this case, the buildings are already isolated quite well, and the outdoor pollution is the greater issue than the indoor (no comments from the questionnaire addresses the noise problem to include the noise level indoor). This supports the two other as possible solutions. To investigate the effect of a noise barrier, a simulation with a noise barrier identical to that of the E47 is established parallel to O3 in the new simulation. In Figure 10 on page 26 it is seen that the noise barrier more or less stops the sound and provides an L_{den} of only 50.5 dB in the garden of Spot 1 and 50.4 dB in the garden of Spot 2. This is a reduction of more than 10 dB at the two receiver points. The result at Spot 3 is as expected unchanged.

A noise barrier could be a good solution, but it has to be taken into consideration that it will decrease the amount of sunlight in the gardens and buildings, especially because it is placed south of the gardens. Furthermore it might not be the aesthetic wish from the municipality to cover the trees with aluminium. However, further down the road of O3, closer to the city of Herlev, noise barriers of coated glass is placed. These designs could be of interest in this case.

6 Conclusion

During the study, questionnaires were distributed, measurements have been conducted and simulations of the road noise has been performed. These have been revealing great concerns regarding the noise level within the residential area of Herlevhuse.

From the noise map developed by the Danish Ministry of the Environment, it was concluded that 1/3 of the residential area can be considered noise congested with $L_{den} > 58$ dB. The noise congested area includes the roads Hellekisten, Dyssestien, Barkæret, Ardfuren, Runddyssen (odd numbers, approx. 5-29) and Langdyssen (numbers approx. 1-54) as marked by the purple line in Figure 11 on page 29.

The noise map also frames the residences located directly close to Ring Road O3 as heavy noise congested with $L_{den} > 68$ dB. This includes the equal numbers of Langdyssen (approx. 2-34) and is marked by the dark purple line in Figure 11.

The survey showed tendencies addressing the noise problem among the residents to also mostly include residences near O3. However, it should be kept in mind that 2/3 of the returned questionnaires derived from the noise congested area.

45 % of the residents (whom attended the survey) is 'annoyed' og 'very annoyed' by noise.

15 % of the residents address the noise to derive from O3.

Several comments mention the ambulance sirens as a huge problem.

Measurements in three spots were conducted and an L_{den} value was calculated for each spot. The noise level in the two spots located close to O3 added up to an L_{den} value above 58 dB and was thus, in the time of measuring, noise congested. Although the measurement cannot conclude a noise problem as a standalone, it can be used to support the findings of a simulation.

In a comparison with the noise map, the measured L_{den} values fit very well with the those in the spots on the noise map.

The simulation of the situation during the time of the measurement conduction revealed some of the same problematics as the noise map showed. The noise from O3 is of great concern for the nearby located residences.

In contrast to the noise map, the simulation included O3 and Highway

E47 as noise sources only. And even though, noise from O3 still impacts the residences nearby.

Another simulation of the same situation but added a noise barrier at the north side of O3 reveals that the noise level in the receiver spots 1 and 2 dropped from 62.1 and 61.0 to 50.5 and 50.4 respectively, i.e. below the threshold of 58 dB.

Although the scope of this report not includes the formation of political decisions or support for these, it will conclude that there is basis for further professional investigations of the noise congestion in the area. The conclusion also draws the attention towards the the fact, that a solution of a noise barrier along the northern side of O3 has proven plausible to reduce the noise level in the residential area of Herlevhuse.

Last but not least, it shall be stressed, that further professional investigations and political decisions must include the unique factor of the extra amounts of bypassing ambulances with sirens. These make a lot of noise, both outshouting the regular traffic and creating a more annoying uneven noise pattern. Leaving these out of the calculations and decisions (i.e. like the noise map does) should not be accepted.

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