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Report

Outdoor and indoor noise in bedrooms
A case study from Oslo

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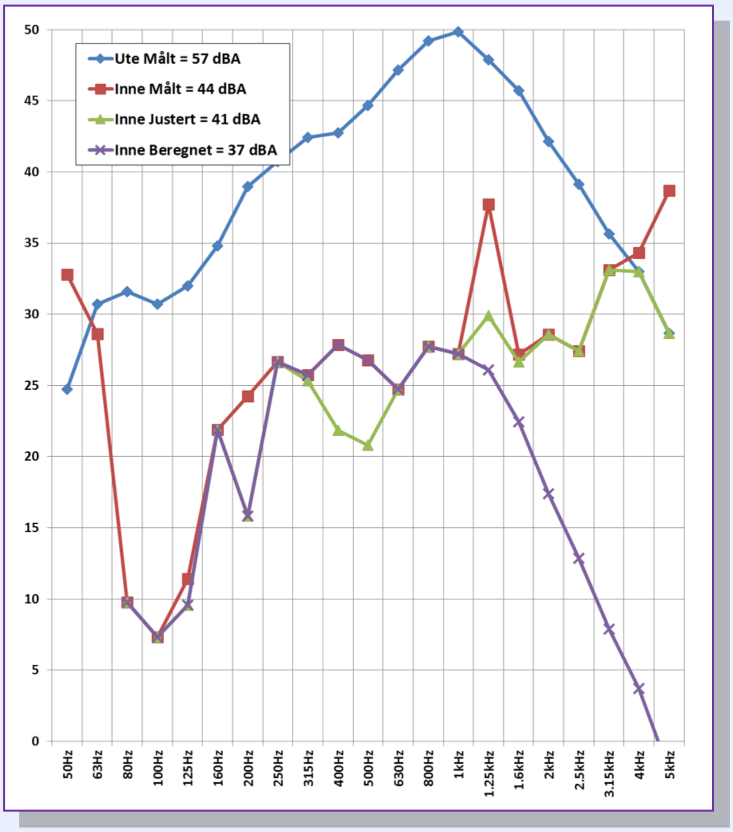

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ABSTRACT

Indoor noise exposure in children's bedroom has been studied by SINTEF Digital. It is a part of the MILPAAHEL project "Environmental noise and childrens`s sleep and health - using the MoBa cohort", at The Norwegian Institute of Public Health.

The findings tell us that indoor night-time noise in children's bedrooms often is dominated by indoor noise sources, but that this differs largely from case to case. Also, there seem to be little correlation between noise on the most exposed facade, and the noise on silent side.

A new low-cost methodology has been developed for collection of indoor and outdoor noise exposure data. This is suitable for large scale measurements of very detailed data, with valid quality.

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Document history

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1.0	2017-10-18	Release

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APPENDICES

1 Background

Outdoor noise is a growing environmental problem in modern urban society. Transportation traffic on roads, railways and aircraft causes noise exposure on human beings in the surroundings, with negative effects on their well-being and health.

A research on noise effects on children during sleep has been conducted by The Norwegian Institute of Public Health. It is titled "Environmental noise and childrens`s sleep and health - using the MoBa cohort", and funded by The Norwegian Research Council as a researcher project under the MILPAAHEL programme. It lasted from 2013 through 2017. The project is hereafter referred to as the sleep study.

One activity in the project has been to characterize and quantify the physical noise exposure to children during night-time sleep in their bedrooms. This task has been carried out as a separate study at SINTEF Digital. The study and its results are presented in this report. It is referred to as the exposure study.

2 Objectives

The objective of the exposure study has been to contribute to closing knowledge gaps in three specific themes:

- What is the outdoor noise levels on typical building facades?
- What is the typical sound insulation of bedroom facades, in actual use?
- What order of statistical variations in noise can be expected across selected bedrooms?

A condition was to find answers through case studies of actual noise in the bedrooms of a selected subset of children from the research project.

3 Methods

Environmental noise is normally quantified as the long-term average exposure to building facades and outdoor areas. This is done by calculations according to commonly accepted methods and dedicated software tools. Outdoor noise has been calculated for a population of 200 children in Oslo, who are included in the sleep study. This is as sub-population of a larger group, the so-called MoBa cohort.

The basic method to reach the objectives in the exposure study is to do detailed analyses of the noise exposure for a small set of representative cases. The implied hypothesis is that this will reveal findings that have general application and value.

In the exposure study, a small subset of the sleep study population was selected. The purpose was to do detailed measurements of actual in-door and out-door noise, and collect empirical data for further analyses. Selection criteria was to have a spread of cases to span the typical variation of outdoor noise, building types and bedroom locations relative to the dominant noise source. Additionally, the bedroom had to be accessible for acoustic instrumentation and measurements. The most prominent factor to limit the extent of the study is the cost of doing measurements. To counteract this, a low-cost measurement setup and -procedure was developed and used.

For each of the selected children, noise measurements were made inside and outside their bedroom. One indoor microphone was flush mounted on the wall, close to the pillow of the child's bed. The purpose was to get a good estimate of the actual sound exposure during a night's sleep. A second microphone was mounted on the outside of the main window for the same room, at a point (height) which corresponds to standardized calculation or measurement of outdoor noise. The purpose was to measure the actual outdoor noise, and to be able to discover correlation between outdoor and indoor noise. In cases where the main facade of the room was facing a silent side of the house, like a back-yard, a third microphone was placed on the opposite or most noisy side of the house. The purpose of this was to discover correlation between noise on the most exposed facade, noise on the silent side, and indoor noise in the bedroom.

A premise for the measurements is that we are not looking for un-polluted noise levels to characterize isolated data for road traffic noise or sound insulation, like it is for standardized methods to target technical documentation. The purpose is rather to explore the actual sound regardless of origin, reasons, propagation paths etc. This means that indoor noise sources etc. that would otherwise be regarded as background noise pollution, are actually welcome because they are real. By applying correlation analyses on time patterns in the noise signals, we are able to separate between out-door and in-door sources anyway.

The raw data from all noise measurements consist of a continuous series of values for sound pressure level measured as L_{eq}, every second. It has separate values for every 1/3-octave band in the frequency range from 50 Hz through 5 kHz. The continuous measurement will preferably last for at least 24 hours. With this time span we will get data for a variety of indoor and outdoor noise situations with a variety of noise sources. Data in daytime will not represent sleep time, but it will contribute to the knowledge of outdoor-to-indoor noise flow. In addition to the noise data itself, a set of metadata is collected including room volume, distance from indoor microphone to pillow and to window, room location in the house, as well as geographical location of the house. In this report, some of this data has been removed or made anonymous to avoid potential identification of individuals.

To enhance the extent of noise data collected with limited resources, a low-cost instrumentation and measurement procedure has been developed. The measurement chain consists of a low-cost microphone, an iPod Touch and an App to do the initial analyses. Each equipment setup is calibrated and tested individually to ensure that the spectral and dynamic response meet the requirements for Class 2 sound level meters, according to IEC 61672. This is regarded good enough for the exposure study. These were the specific elements in the setup:

- Microphone: MicW i436 from MicW Audio, used for outdoor measurements
- Microphone: MicW iBoundary from MicW Audio, used for indoor flush-mounted measurements
- iPod Touch 16GB from Apple Inc., used for sound signal capture
- AudioTools SPL Graph from Studio 6 Digital, used for primary signal analyses

A separate SINTEF project note "Vurdering av lavkostnad støyloggere" (in Norwegian), dated 2014-02-03 gives further details about the instrumentation and its performance.

One such instrument setup was deployed for each microphone position, during the measurements. They were run in parallel, with synchronized clocks, to facilitate timeline correlation between the measurement signals. The outdoor equipment was run on the internal iPod battery, while the indoor had mains power.

The measurements were made on locations in Oslo, while the noise experts are in Trondheim, 550 km away. To limit costly work- and travel time by professional expert, a student in Oslo was trained to set up the instrumentation, collect meta-data, and to initiate the measurements. After ended measurements, normally two days later, the same student took down the instrumentation and shipped it all to SINTEF in Trondheim for further data download, quality control, and new instrument recalibration. The equipment was then returned to Oslo for use on the next measurement location.

By this procedure, the measurements were effectively unattended. 1/3 octave band raw data have been collected at each microphone at a rate of one spectrum per second. To get good use of the results, a set of filters and additional analyses has been applied:

- Background noise filter to remove samples influenced by static noise thresholds of the instruments.
- Sanity check to remove suspicious data that are outside reasonable limits
- Events detection to identify noise events similar to car- or train pass-by, or short-time transients in the signals
- Correlation analyses to determine whether or not indoor events origin from outdoor sources
- Aggregation of correlated events to establish statistics on outdoor-to-indoor differences (e.g. sound insulation)
- Aggregations to establish noise levels at night-time
    - Measured outdoor noise
    - Measured indoor noise
    - Estimated indoor noise from outdoor sources
        - Upper level, from the measurements
        - Most probable level, from additional calculations
- Visualisations to enhance the accessibility of statistical results

The analysis algorithms have been developed and implemented in a software program specially developed for this project. Parameters have been tuned to give best functional performance for the actual data sets.

4 Collected data

During the project, data have been collected from 8 locations in Oslo. For all of them the dominating noise source is traffic from roads in the vicinity of the building. The A-weighted noise levels are given in table 1. They are all measured during weekday(s), with normal traffic conditions. Underlying spectral data are given in appendix A. Statistical spread associated with the spectral data is available as separate data sets in an Excel spreadsheet file, which can be obtained from SINTEF. Raw data and filtered data, comprising 1-second 1/3-octave levels and level differences, are also available as ASCII data sets as well as spectrograms for visualization.

The continuous noise levels were reasonable stable during the measurement time, compared to normal expected variations. Variations in outdoor noise levels across the measurement locations are believed to represent the spread in average outdoor noise at the bedroom windows. The variations in indoor noise and outdoor-to-indoor differences are also affected by significant indoor noise during the measurements. This is regarded as normal.

Although the short-time outdoor-to-indoor differences vary a lot from event to event, during the measurements the shown average values can be read as reliable estimates of average situations. Overall, the results should be regarded as good representatives for the actual noise at the given locations.

Table 1: Main result – A-weighted outdoor and indoor sound pressure levels L_{eq}

Location	**Night-time**				**Day-time / Evening**		
	Outdoor	**Indoor**	**Indoor from outside**	**Diff. out-in**	**Outdoor**	**Indoor**	**Indoor from outside**
Location 1	48	32	21	27	55	53	32
Location 2	36	41	18	18	51/48	32/37	23/29
Location 3	49	29	16	33	55	31	23
Location 4	43	44	29	14	57	36	30
	57*		(37)	20	61*		(31)
Location 5 **	38 & 37	45 & 33	28 & 22	10 & 15	48/62	32/40	24/37
Location 6	44	33	21	23	56	31	25
Location 7	28	30	18	10	39	30	25
Location 8	30	43	21	9	40	53	32

* *Microphone was placed on the opposite side of the building*

*** The night period is divided into two parts due to a significant shift in indoor noise (probably closing of a window)*

Red numbers: Can be overestimated due to influence from indoor noise sources

Numbers in parenthesis are unreliable due to poor correlations with outdoor events

5 Findings and evaluations

The results of the measurements have been examined in context of the objectives of the exposure study. The following findings were made:

- Outdoor L_{eq} covers a span from 28 to 48 dBA. This represents moderate to low exposure, compared to established limits for risk of negative effects of noise on human beings.
- Indoor L_{eq} from outdoor sources (road traffic) spans from 16 to 30 dBA. This is regarded as low noise exposures.
- The outdoor-to-indoor noise level differences span from 9 to 33 dB. This represents the expected variations from low sound insulation because of open windows, to good sound insulation of modern building constructions.
- The highest noise levels at night in children's bedrooms were typically not from outdoor sources. Instead they origin from indoor sources associated with normal indoor activity. This may have a masking effect that potentially will obscure observed connections between outdoor noise and children's sleep, relevant for the sleep study.
- Instantaneous outdoor-to-indoor noise differences vary a lot for locations where indoor noise is dominated by indoor noise sources. It is likely that this has led to over-estimations of indoor noise from outdoor sources. The actual figures may be lower than reported for these locations.
- It is very hard to find good correlations between measured noise on the most exposed facade, and a bedroom facade on the silent side. This means that future measurements should focus on the actual facade of the bedroom instead of the most exposed one. This also emphasizes a requirement for noise mapping methods to correctly calculate outdoor noise on silent sides of the house. This coincide well with a NTNU Master thesis[1] that was written with guidance support under the exposure study.
- One must expect large variations in indoor noise from place to place, independent of the outdoor noise level. This indicates that outdoor noise exposure may not be the best indicator when considering noise effects on sleep.

In addition to these findings, which concern the objectives of the study, another list of observations need to be mentioned. These represent learnings from the study, concerning the methodology that was applied:

- By applying good filters on indoor noise that separate between indoor sources and outdoor sources, it is possible to quantify very low road traffic noise levels in bedrooms.
- However, noise pollution from indoor noise sources can still impose considerable uncertainty.
- Technically, the use of iMic, iPod, App was a success. The instrumentation was robust, reliable and sufficiently accurate for the purpose.
- This opens for large scale measurement campaigns at reasonable costs.
- However, continuous functional and quality control is important.
- The use of a non-expert person (student) for deployment of the measurements were successful, but one must accept a risk that some data may be lost.
- Sending the instrumentation back and forth with mail worked ok. However, at two occasions we experienced that the package got lost. This was problematic, and eventually led to the campaign being far less extensive than originally planned.
- The organization of the measurement campaign could have been better. Much time was lost due to waiting. This underlines the importance of good planning and communication.

[1] Vegard Wøllo: Lydutbredelse til skyggesiden av tykke skjermer, med spesiell oppmerksomhet på diffraksjonseffekter. NTNU Masteroppgave, Trondheim 2014

6 Conclusion

Indoor noise exposure in children's bedroom has been studied by SINTEF Digital. It is a part of the MILPAAHEL project "Environmental noise and childrens`s sleep and health - using the MoBa cohort", at The Norwegian Institute of Public Health.

New insight has been built through a case study, concerning noise in bedrooms and its connections to outdoor environmental noise. The most important findings tell us that indoor night-time noise in children's bedrooms often is dominated by indoor noise sources, and that this differs largely from case to case. In some cases, this indoor-origin noise is fluctuating considerably compared the outdoor road traffic noise. This may be of importance when modelling exposure-to-response relationships during sleep.

Another important insight is that there seem to be little correlation between noise on the most exposed facade, and the noise on silent side. This implies that when considering noise during sleep, it is important to know the exposure on the bedroom facade instead of only relying on data for the most exposed side of the house. But, the empiric basis for this is still small. More measurements should be made.

During the project, a new low-cost methodology has been developed for collection of indoor and outdoor noise exposure data. Evaluation of instrumentation, analyses and measurement procedures point to a very cost-efficient way for large scale measurements of very detailed data, with valid quality.

A Appendix: Detailed frequency spectra for outdoor and indoor noise

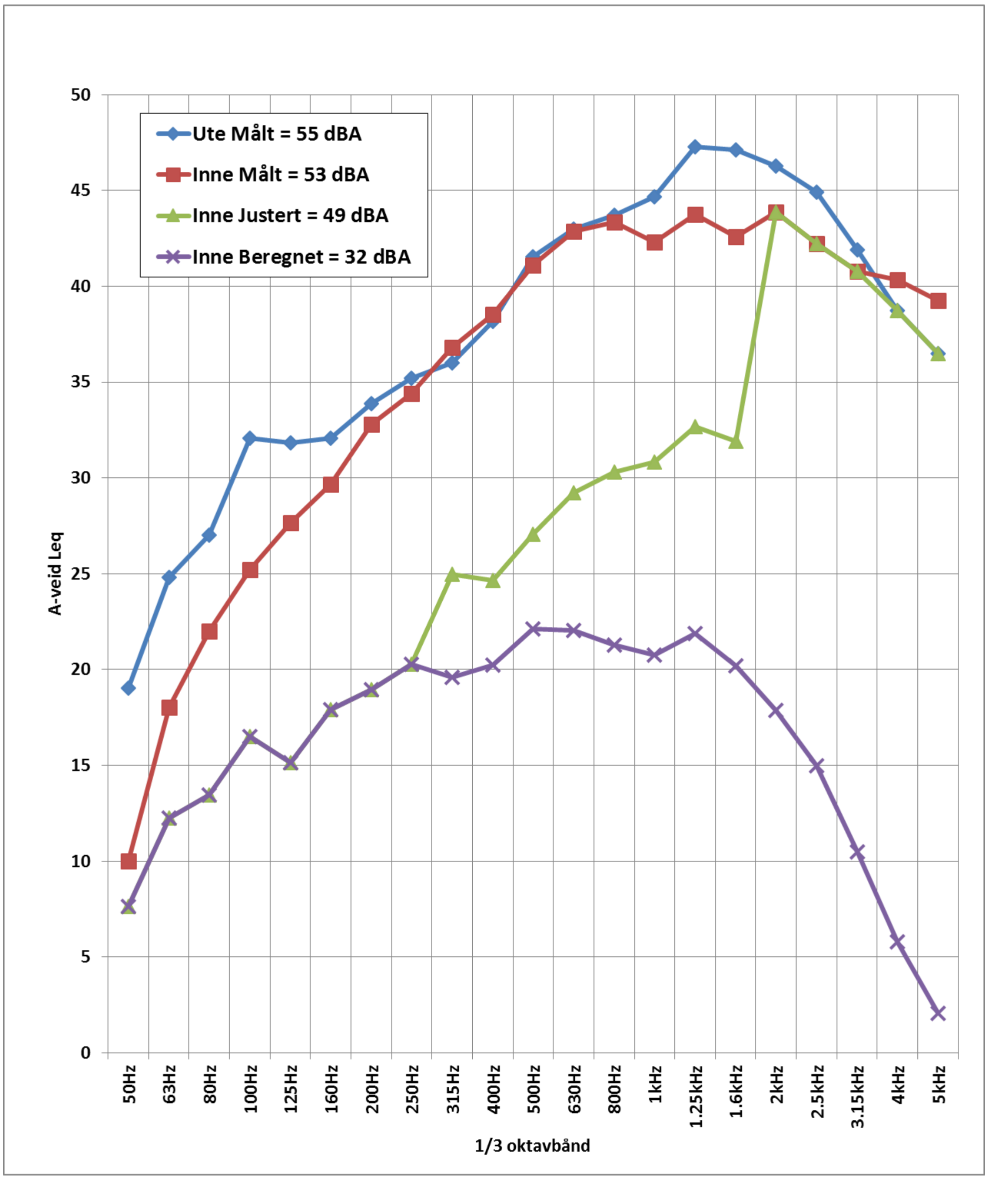
This appendix contains frequency spectra for outdoor noise and the relevant variants of indoor noise. These spectra relate directly to corresponding A-weighted levels shown in the table of main results in the report.

The frequency spectra are shown in the following 21 diagrams. Each of them has four curves:

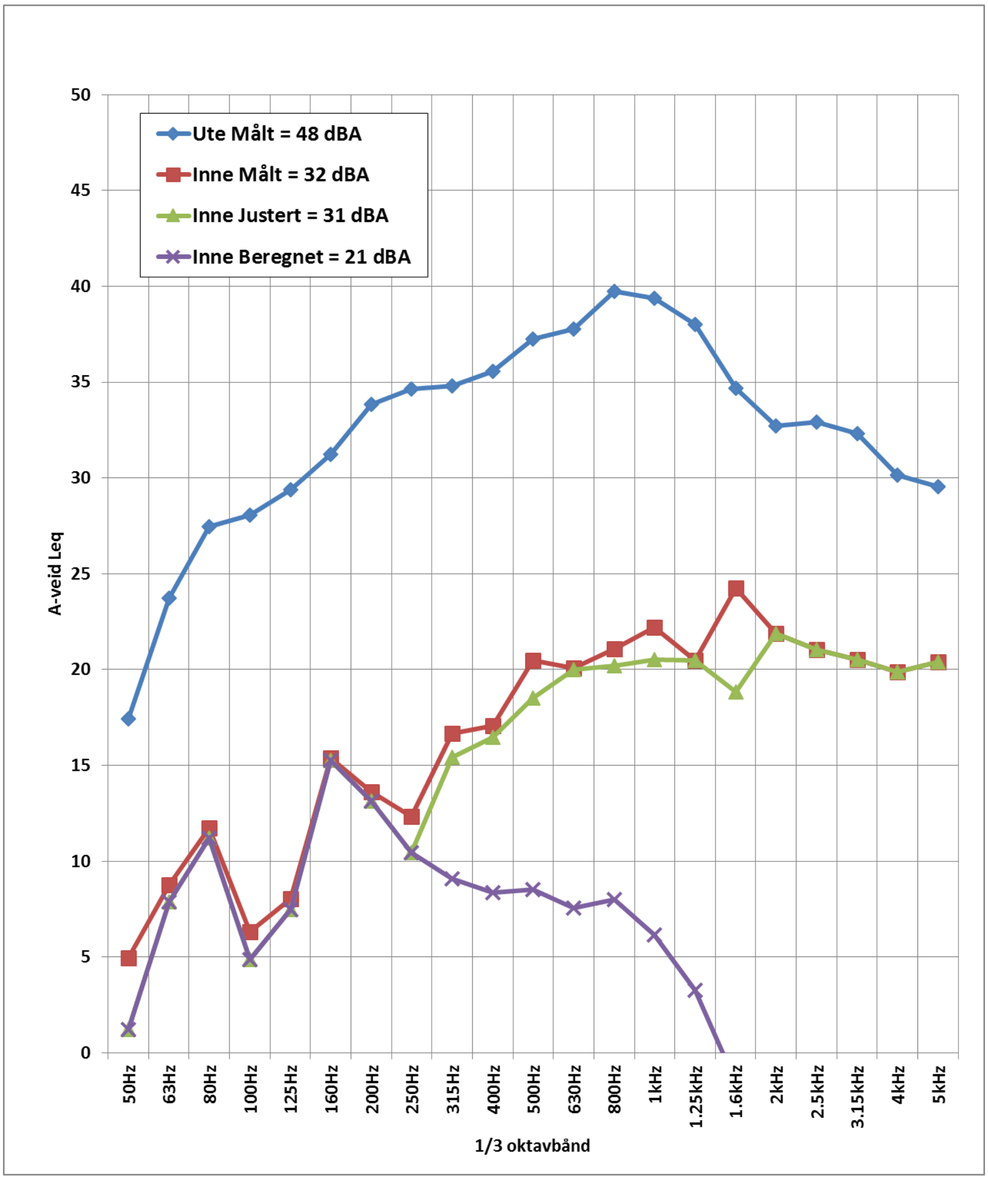
- Blue: Measured outdoor L_{eq} (Ute Målt)
- Red Measured indoor L_{eq} (Inne Målt)
- Green: Indoor Leq after removing uncorrelated events (Inne Justert)
- Purple: Indoor after applying outdoor-to-indoor difference (Inne Beregnet)

The 21 diagrams cover

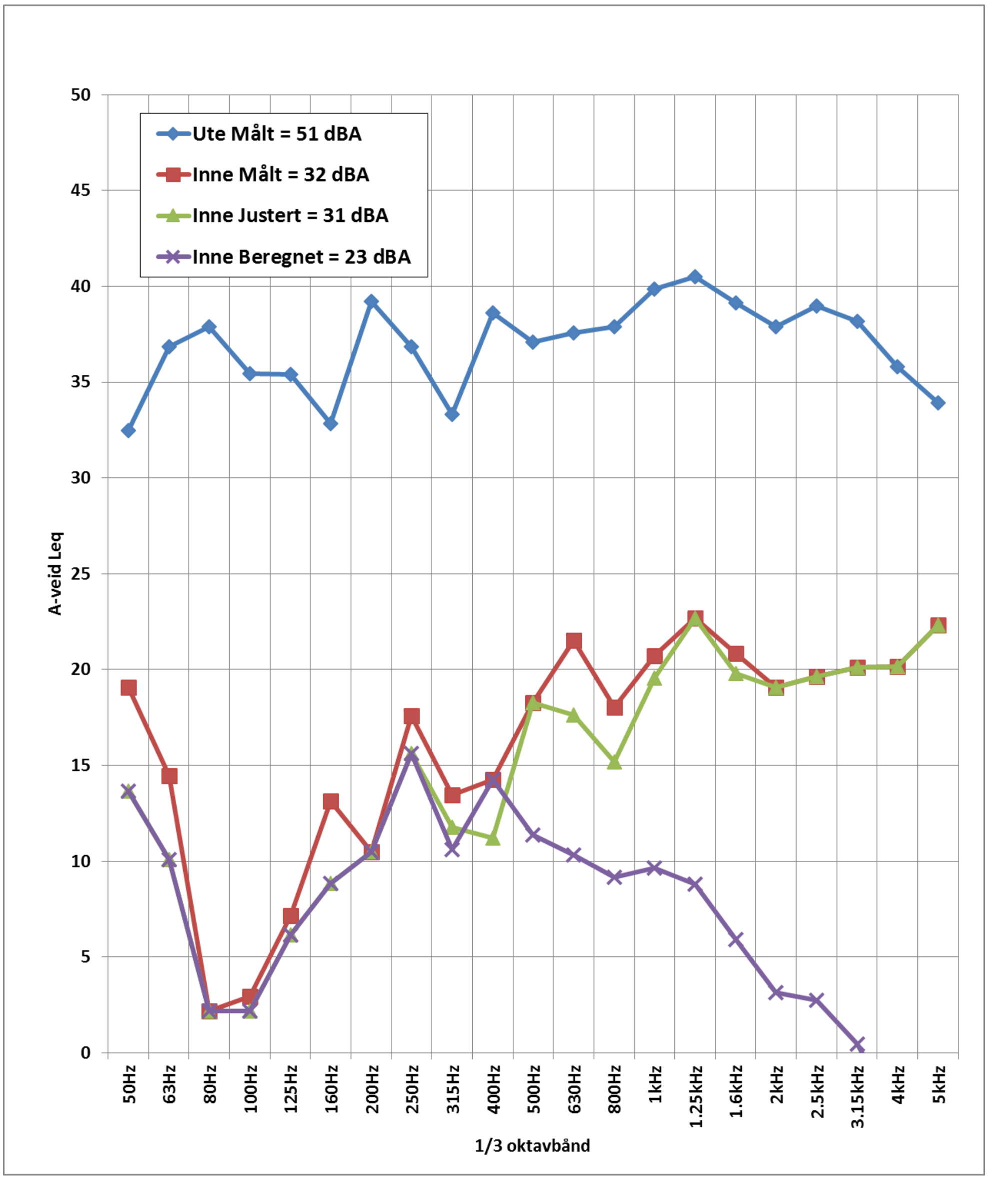
Location 1 – Evening
Location 1 – Night-time
Location 2 – Day-time
Location 2 – Evening
Location 2 – Night-time
Location 3 – Day-time
Location 3 – Night-time
Location 4 – Day-time
Location 4 – Day-time (outdoor mic. on opposite side of the building)
Location 4 – Night-time
Location 4 – Night-time (outdoor mic. on opposite side of the building)
Location 5 – Day-time
Location 5 – Evening
Location 5 – Night-time (first half of the night)
Location 5 – Night-time (second half of the night)
Location 6 – Day-time
Location 6 – Night-time
Location 7 – Day-time
Location 7 – Night-time
Location 8 – Evening
Location 8 – Night-time



Location 1 - Evening



Location 1 – Night-time



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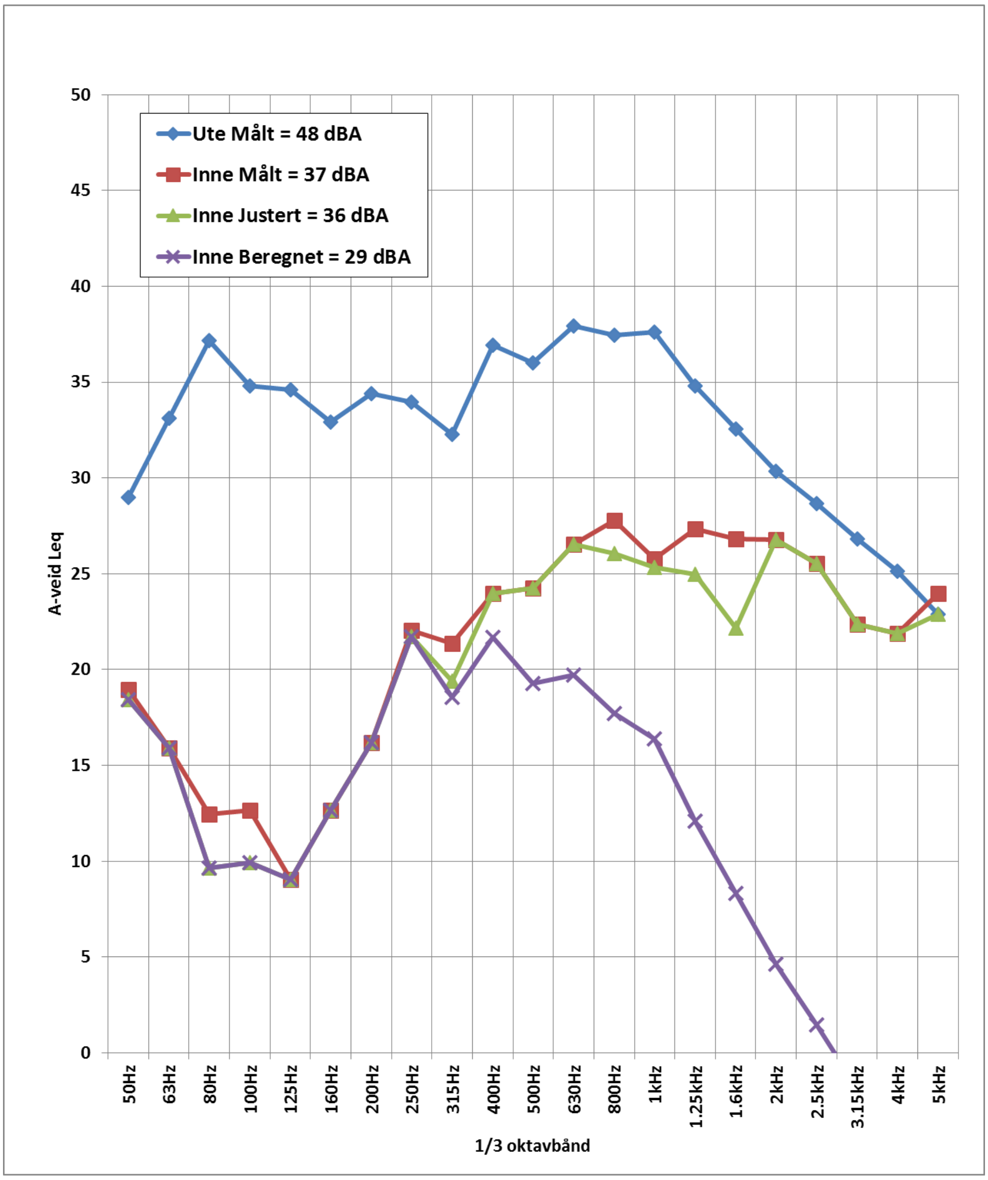
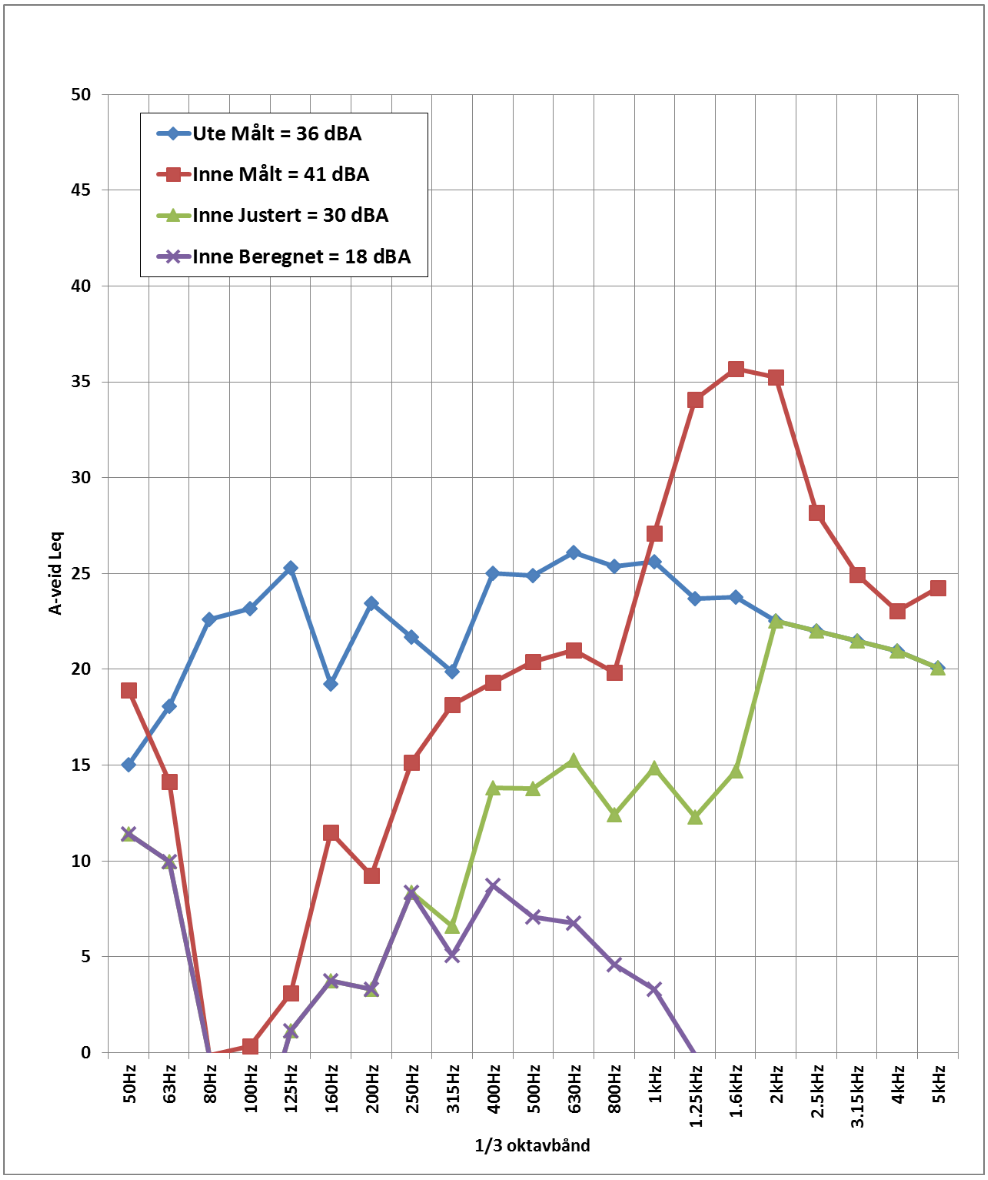
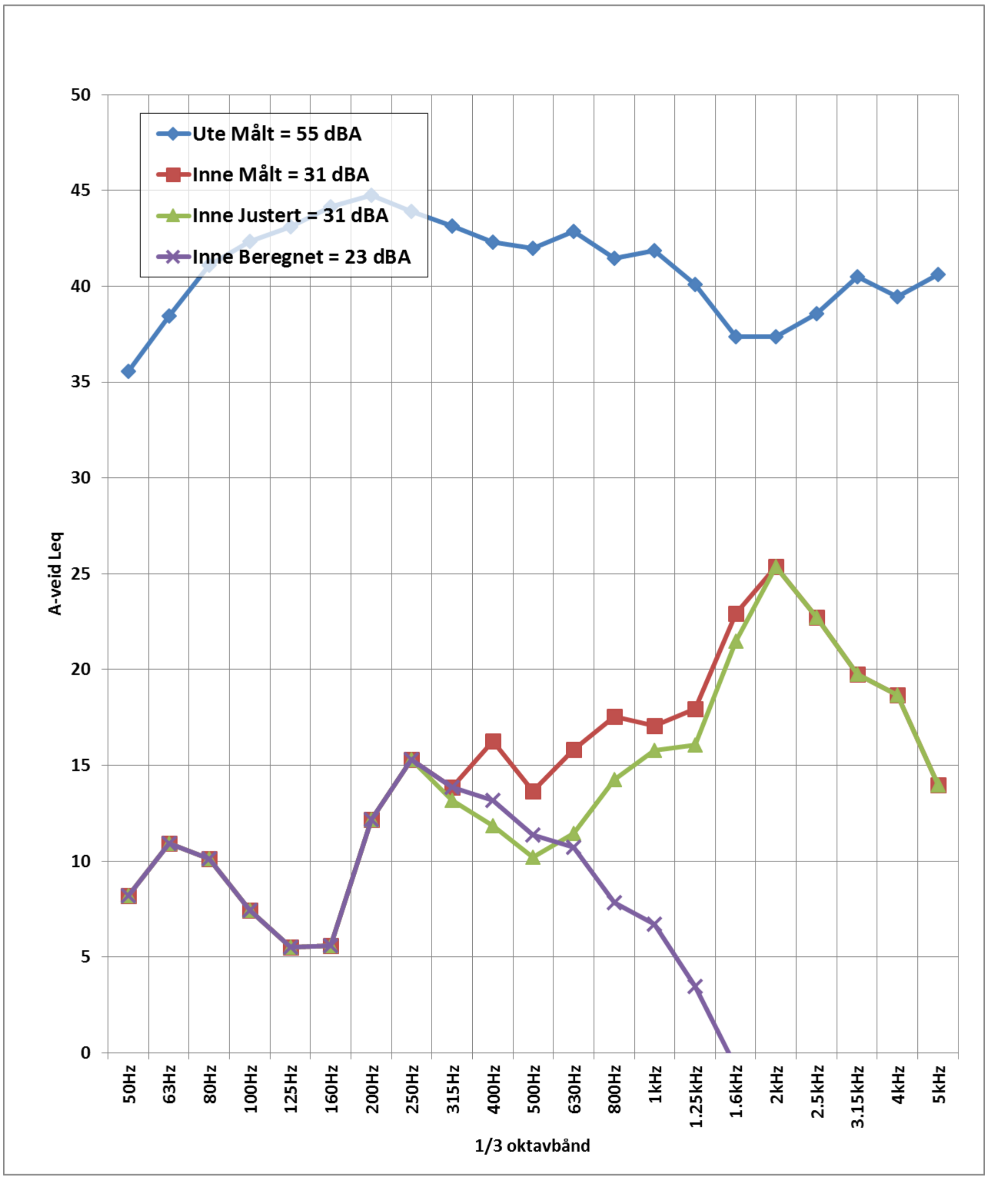


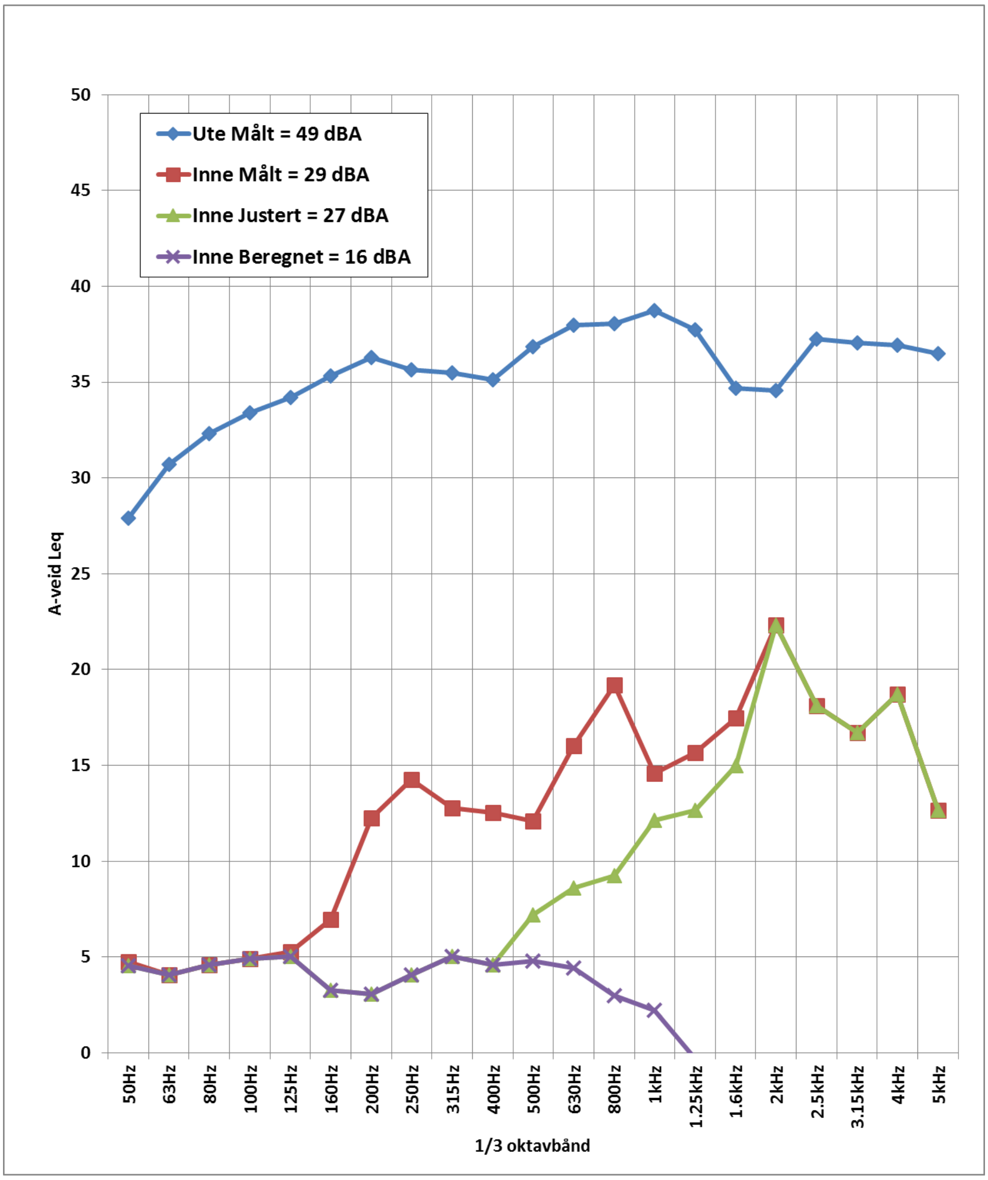
Location 2 – Evening



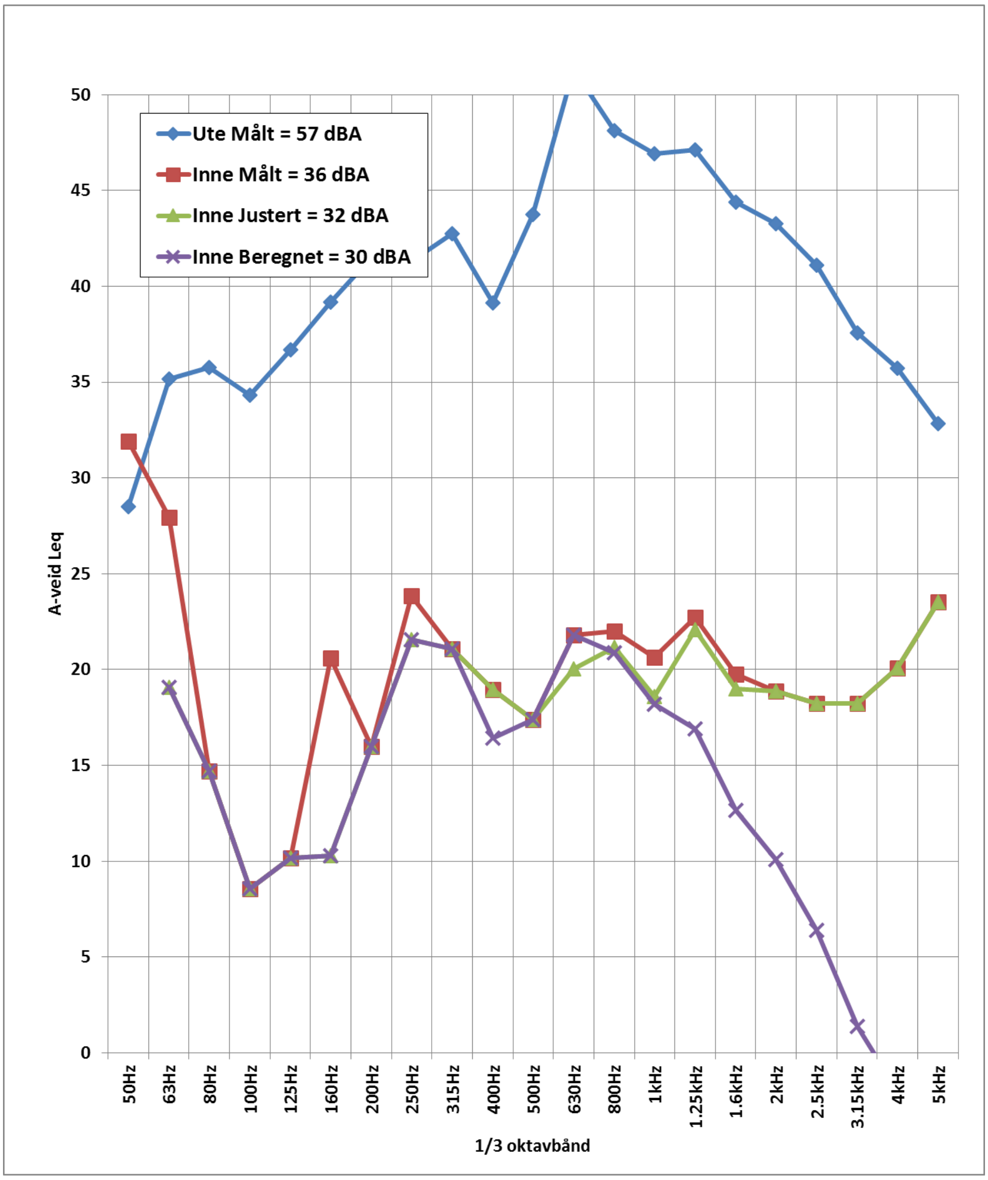
Location 2 – Night-time



Location 3 – Day-time



Location 3 – Night-time



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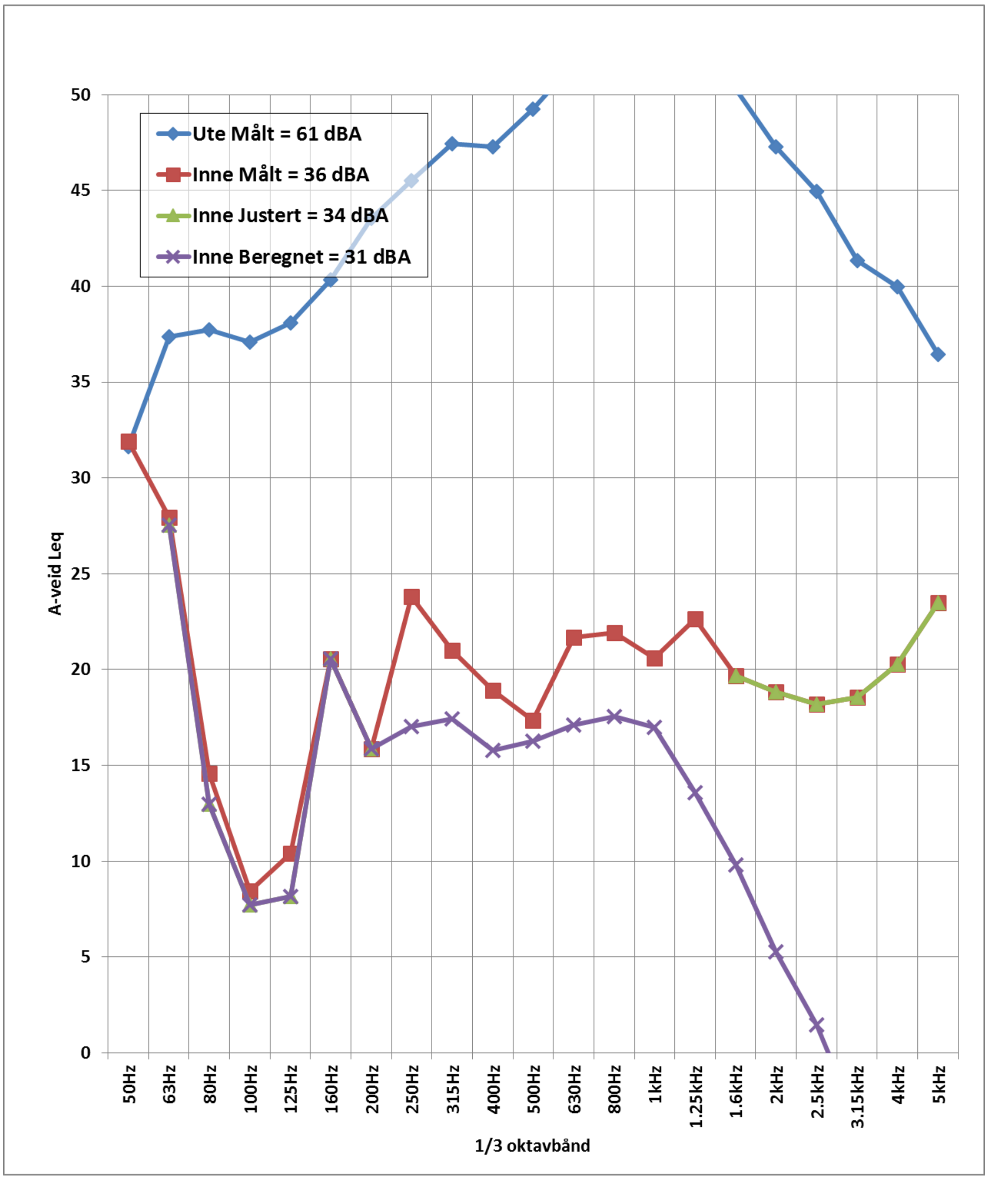
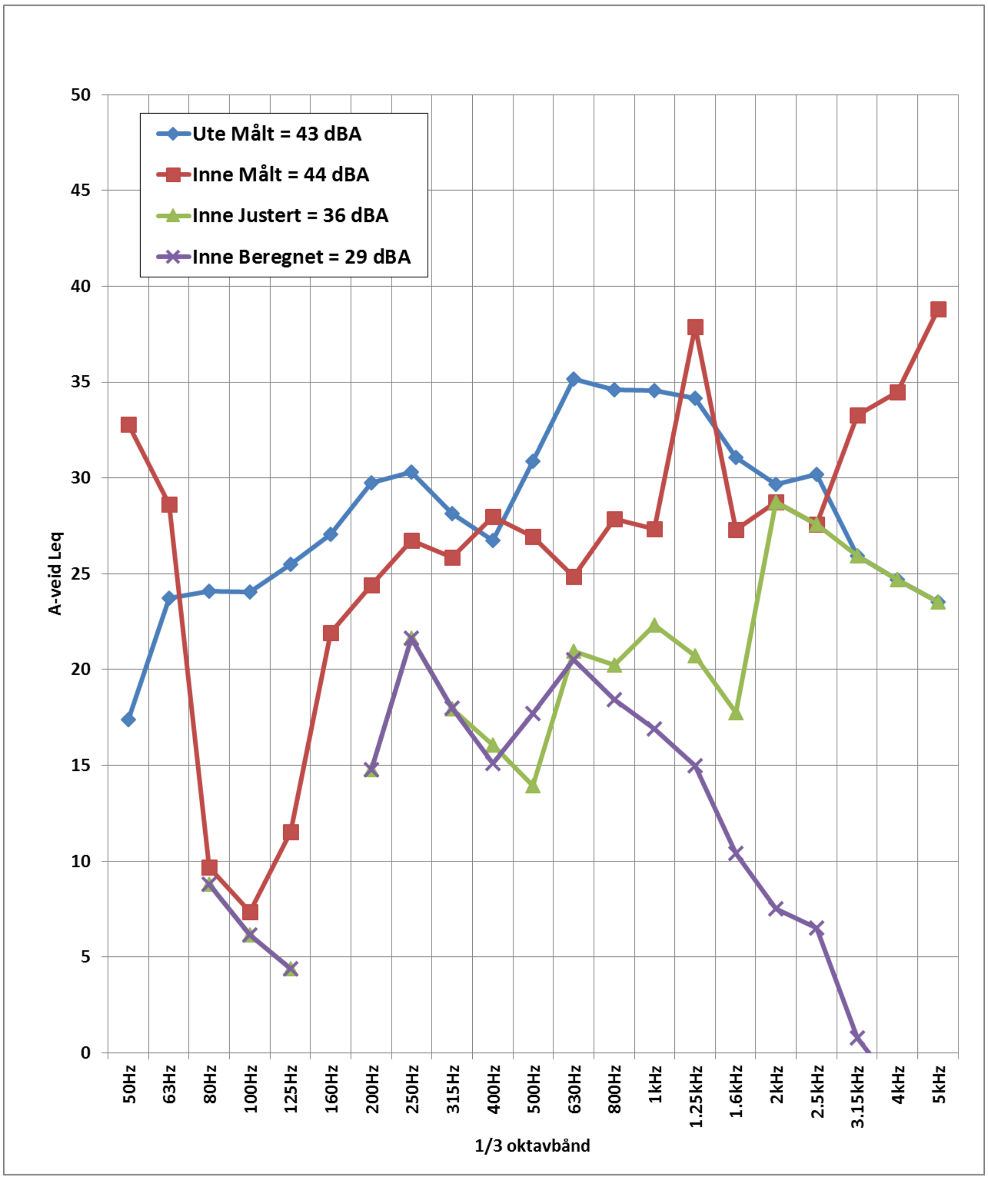
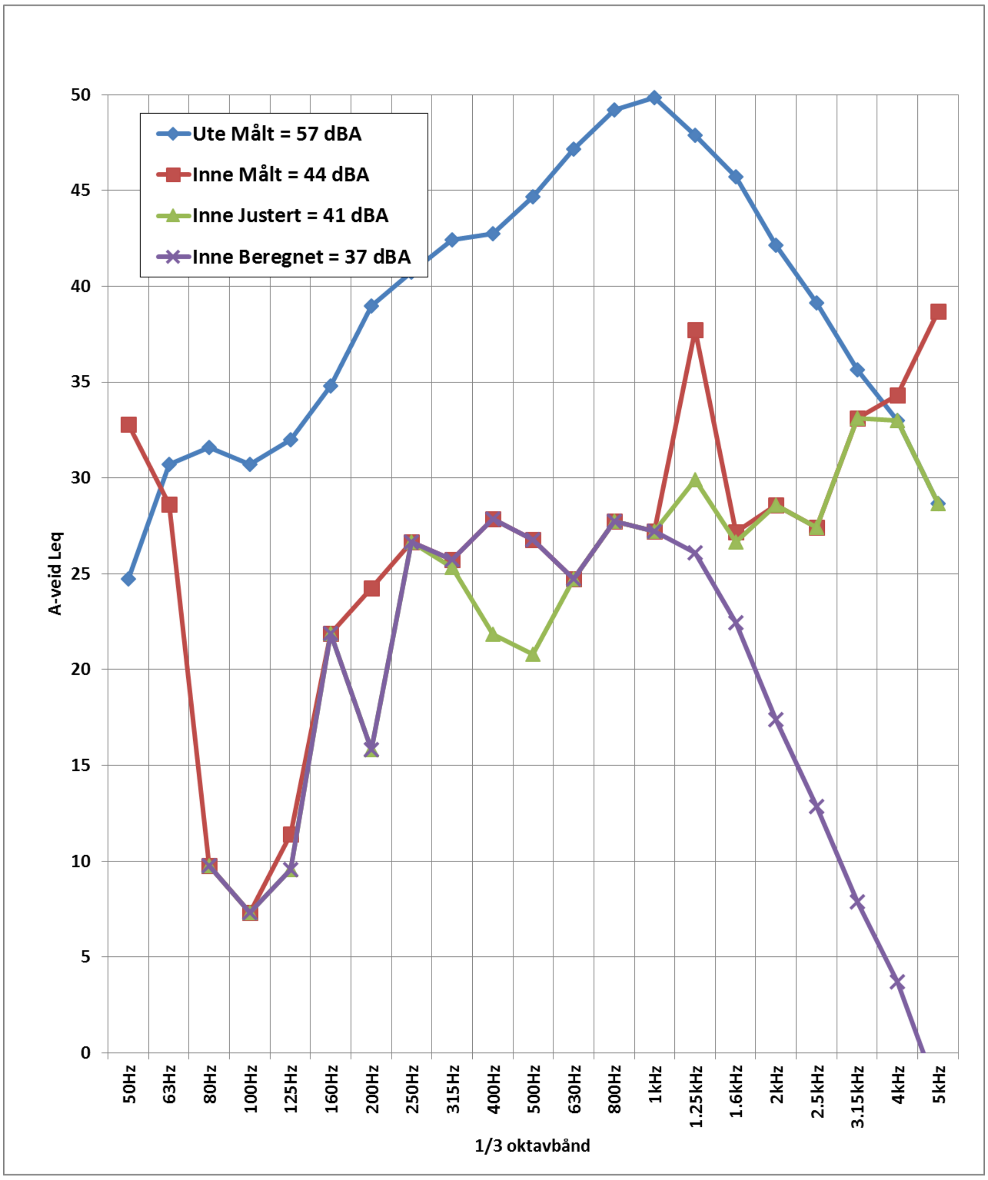


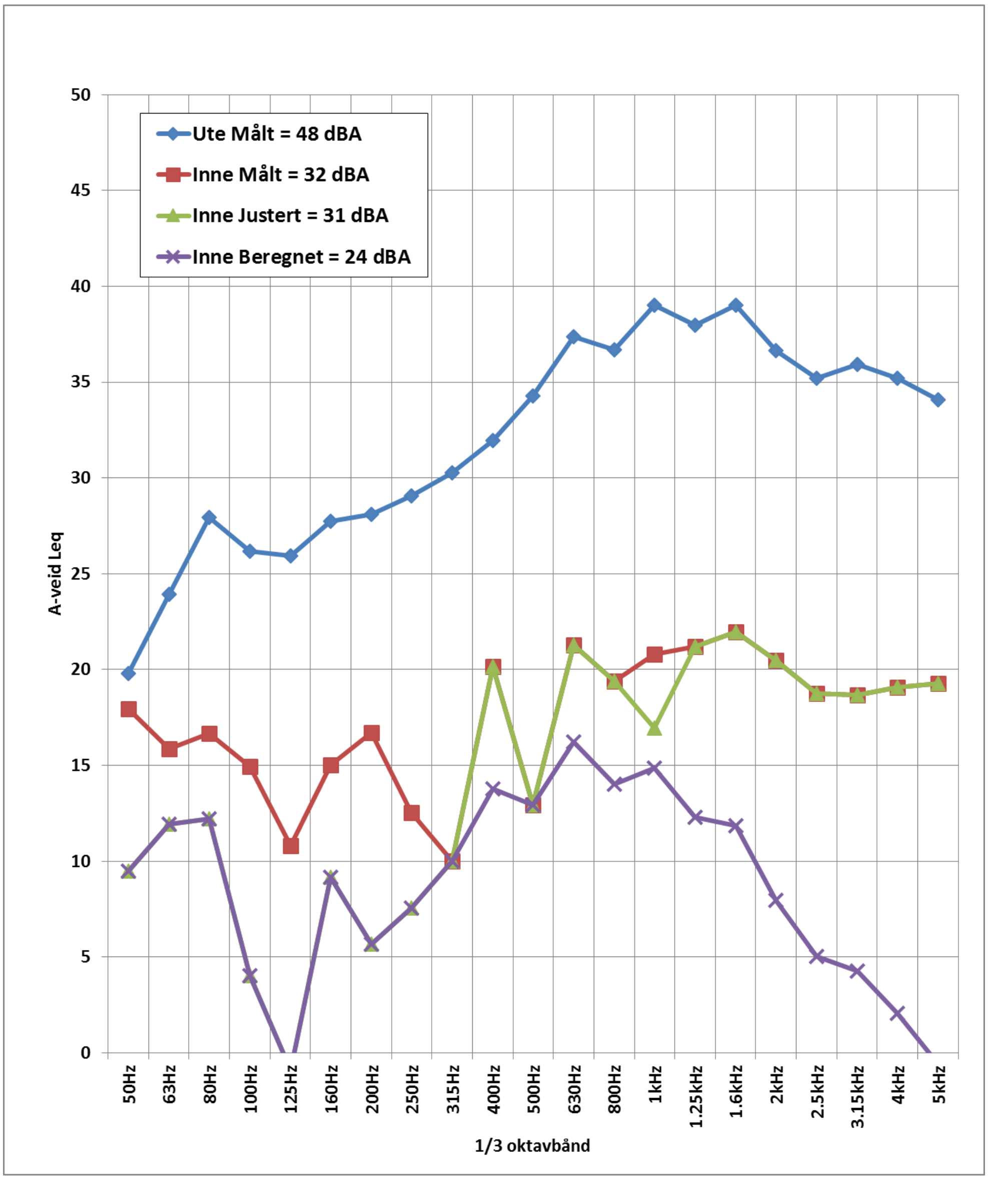
Location 4 – Day-time (outdoor mic. on opposite side of the building)



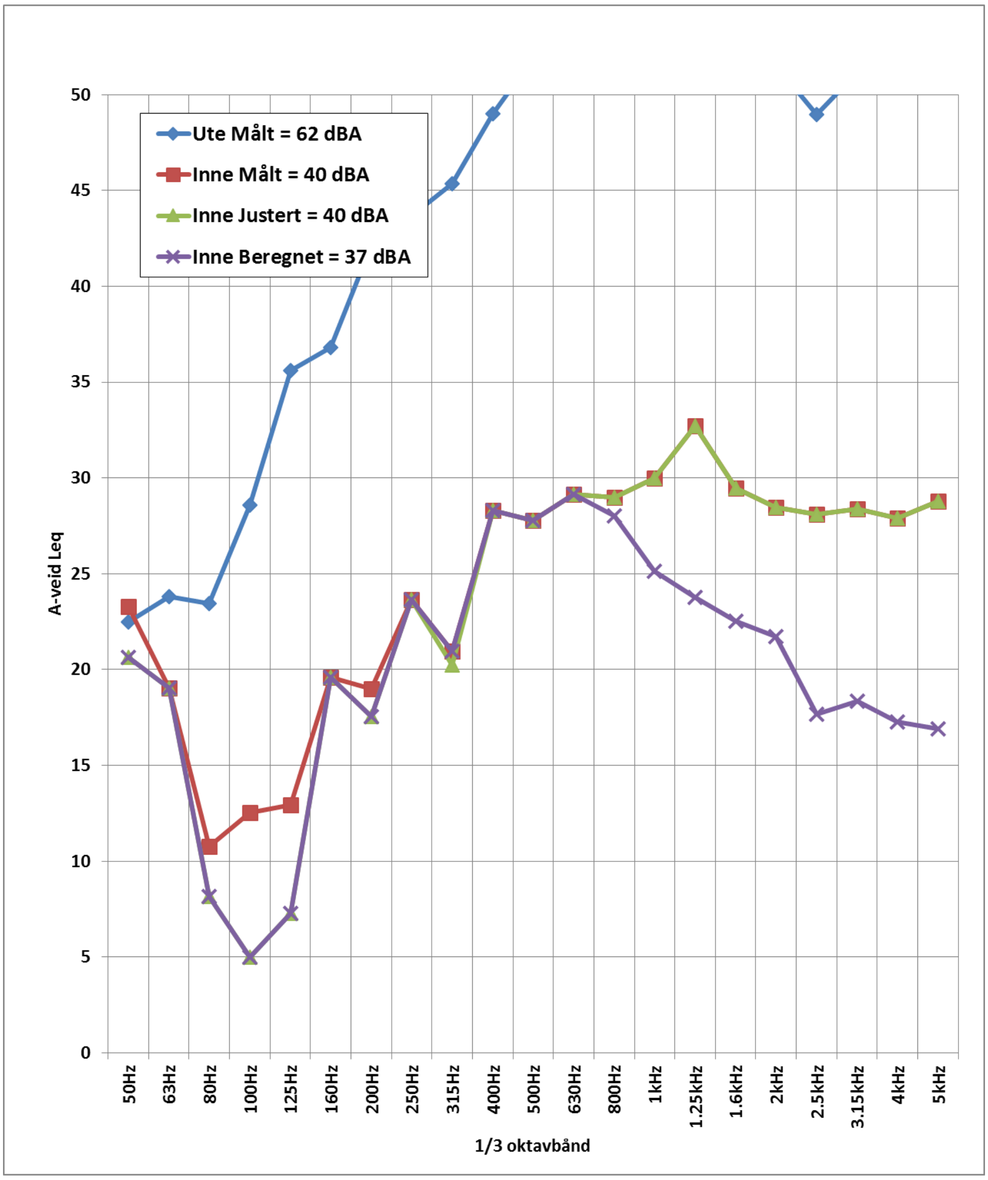
Location 4 – Night-time



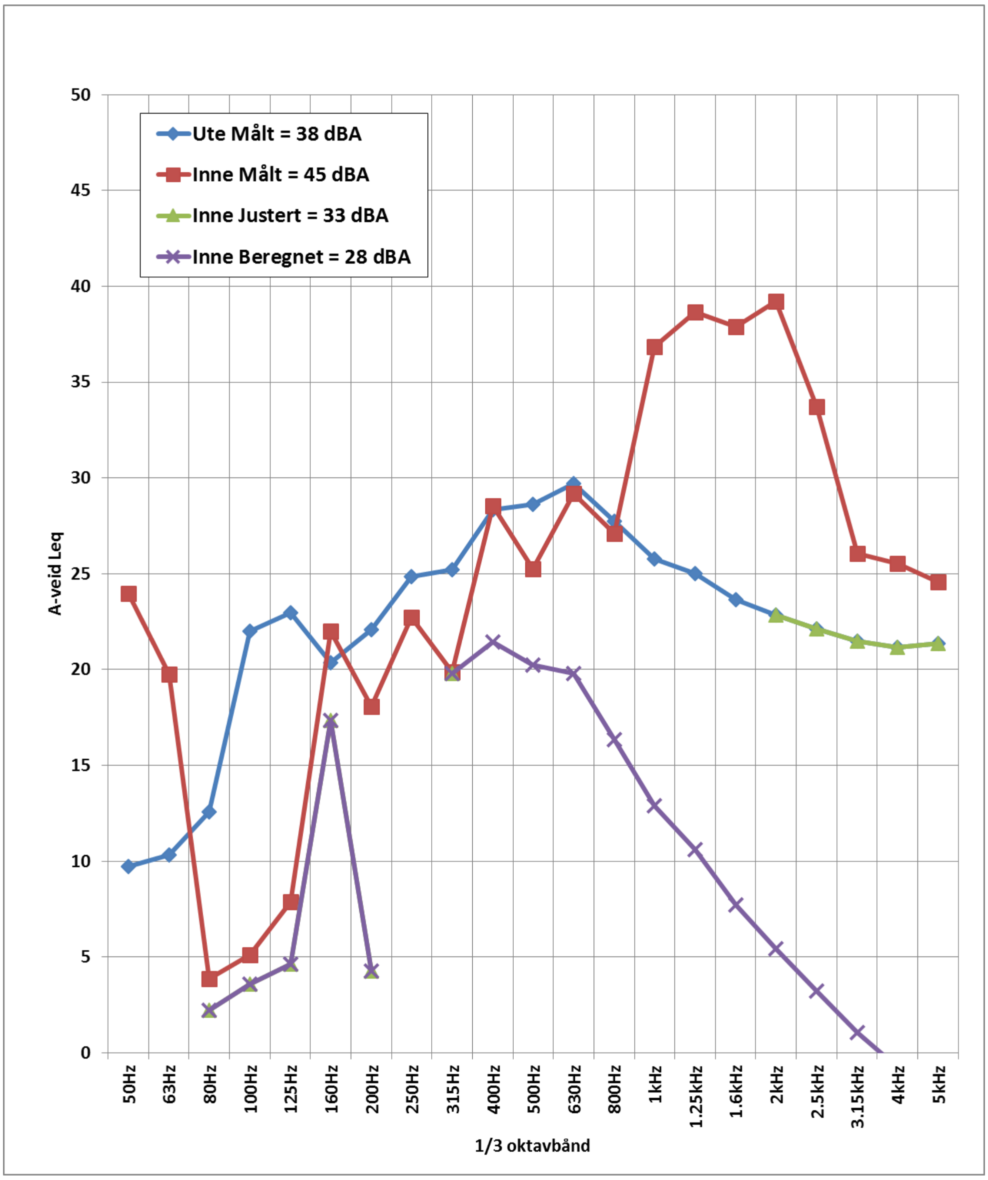
Location 4 – Night-time (outdoor mic. on opposite side of the building)



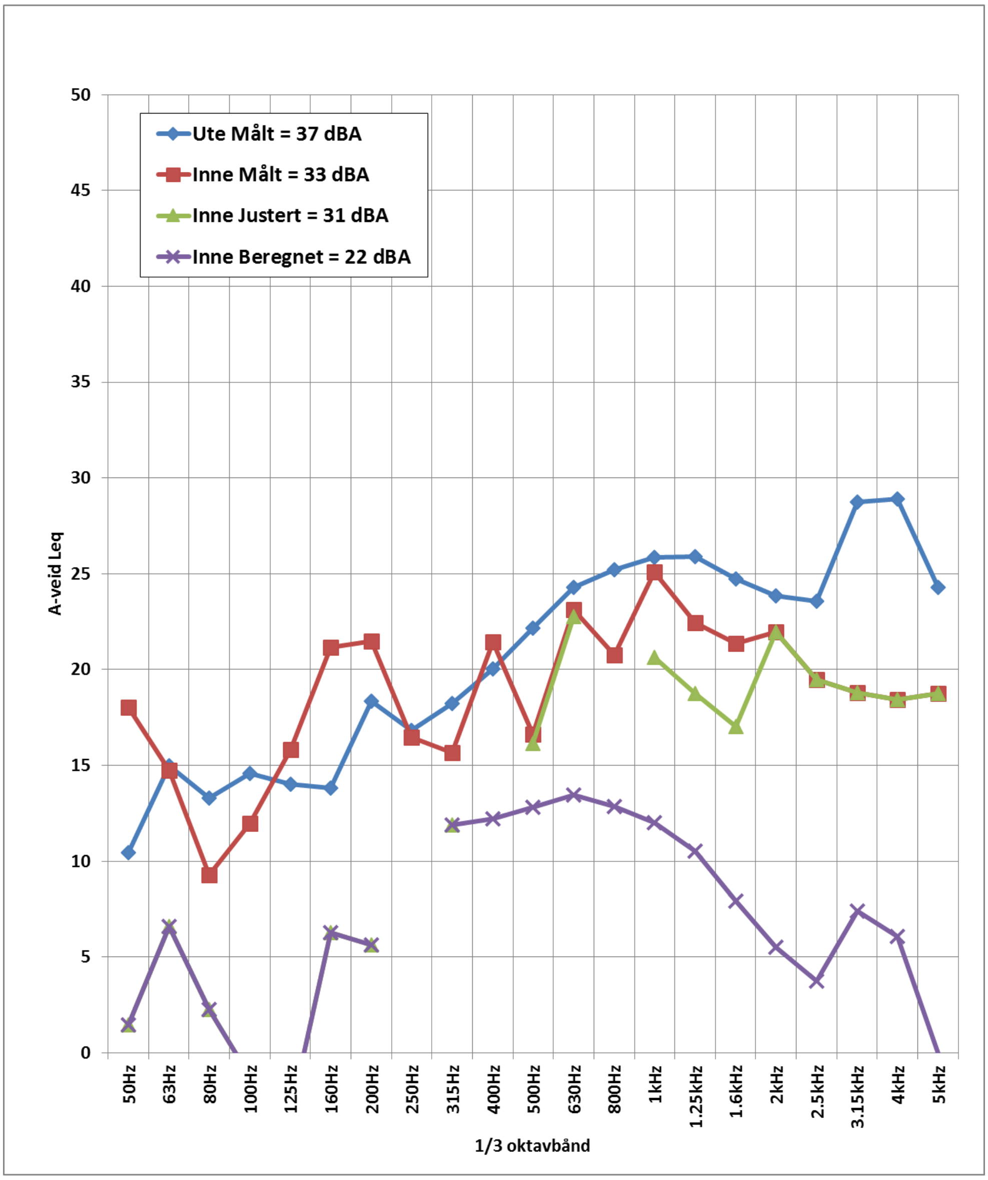
Location 5 – Day-time



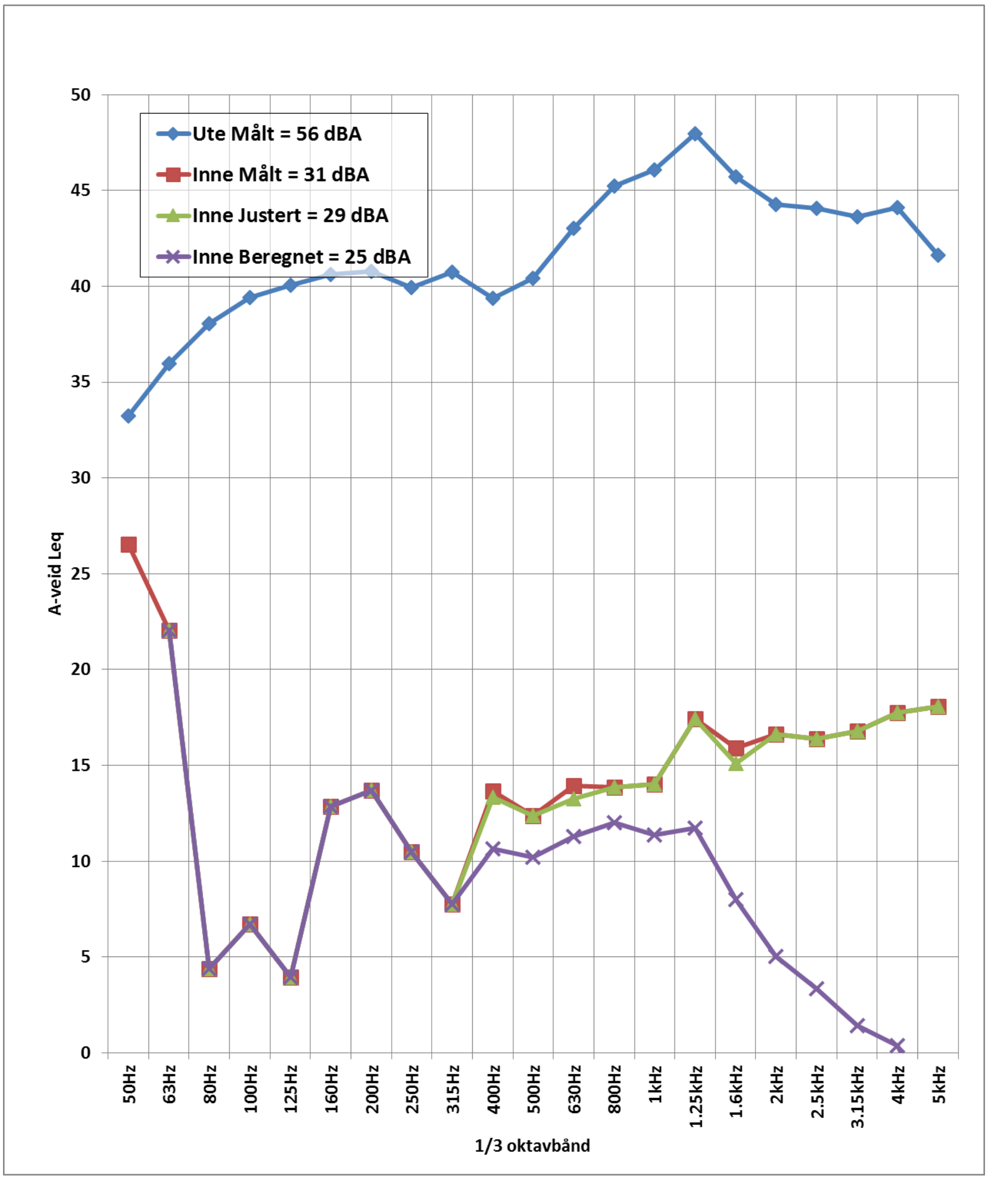
Location 5 – Evening



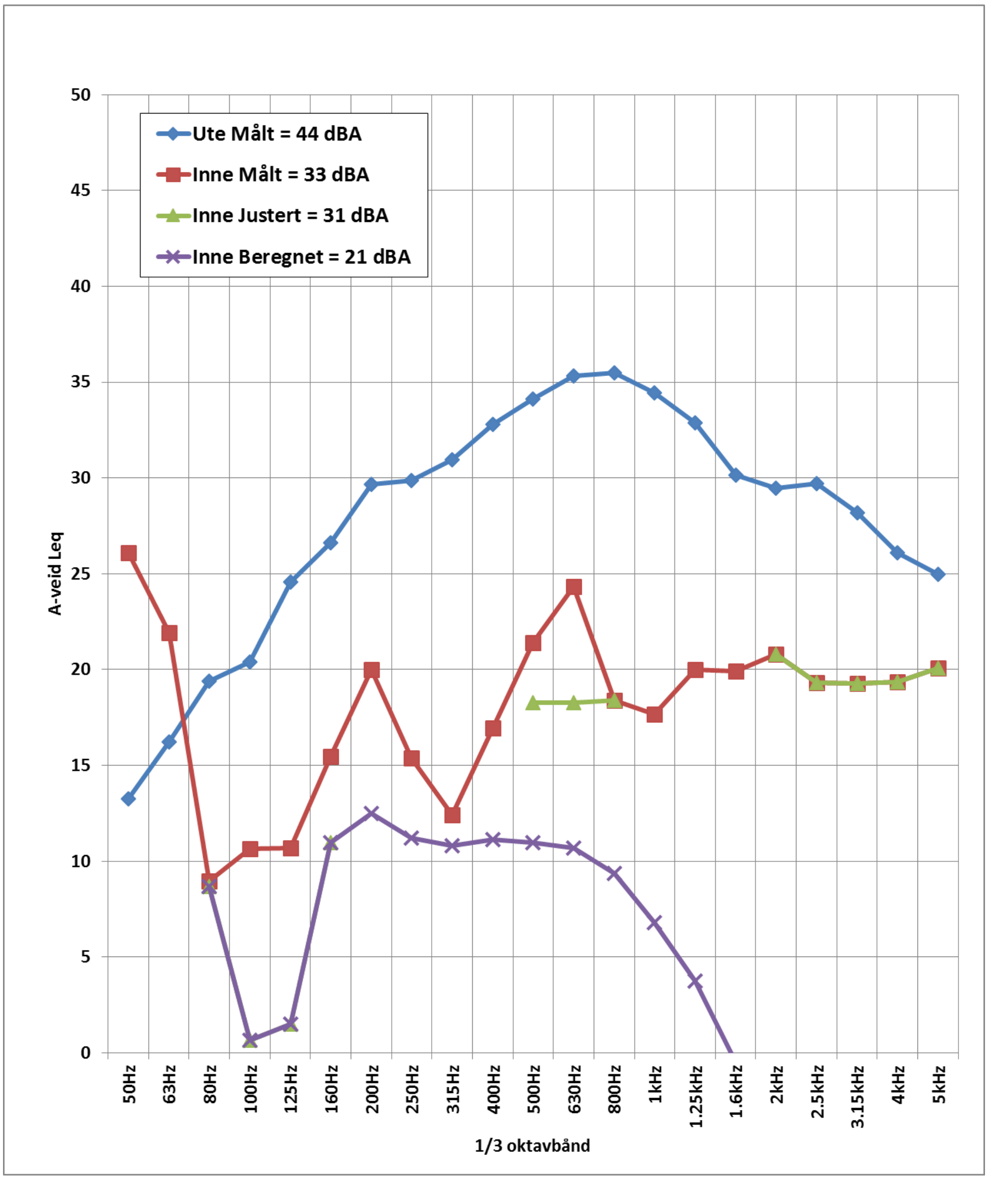
Location 5 – Night-time (first half of the night)



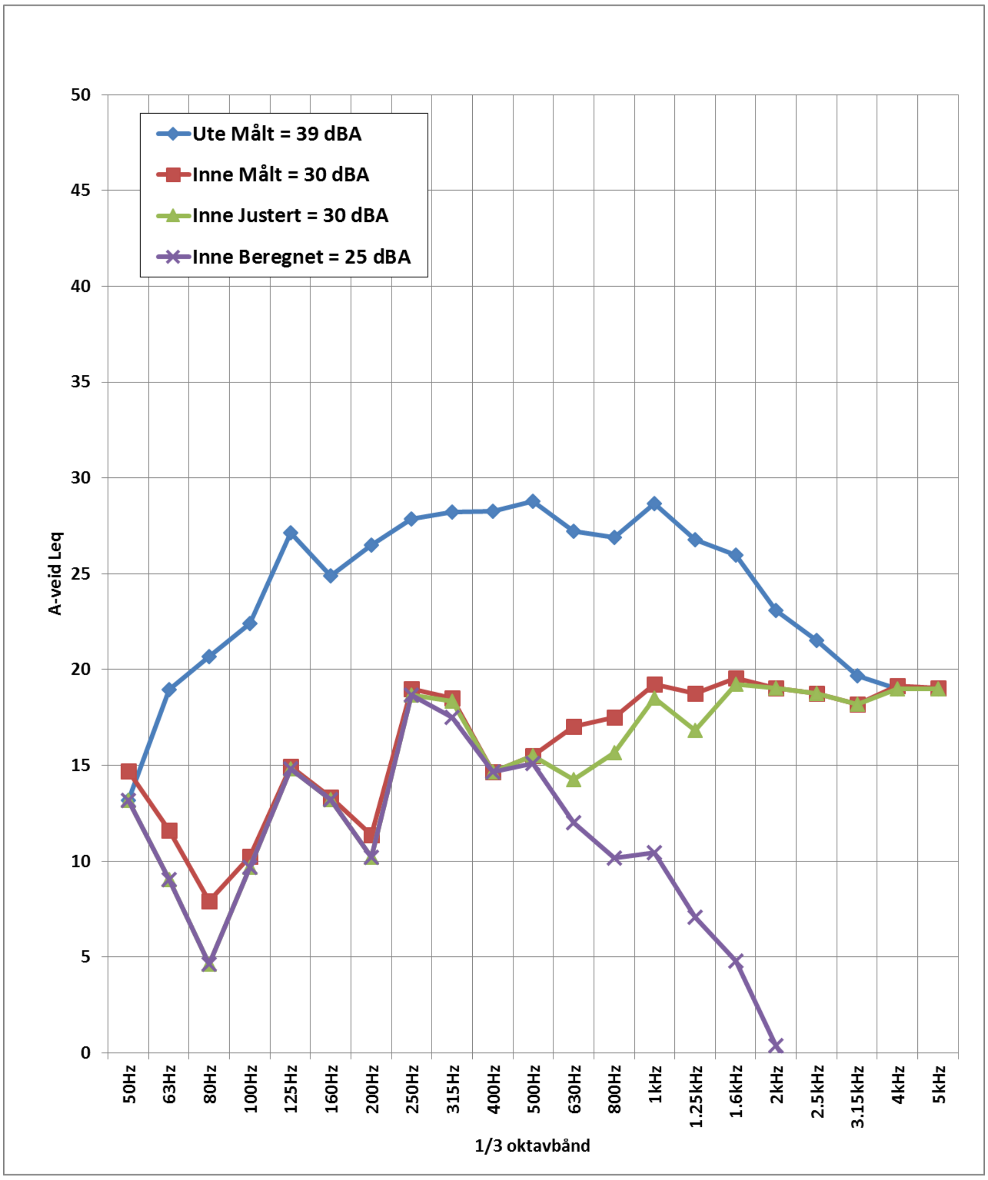
Location 5 – Night-time (second half of the night)



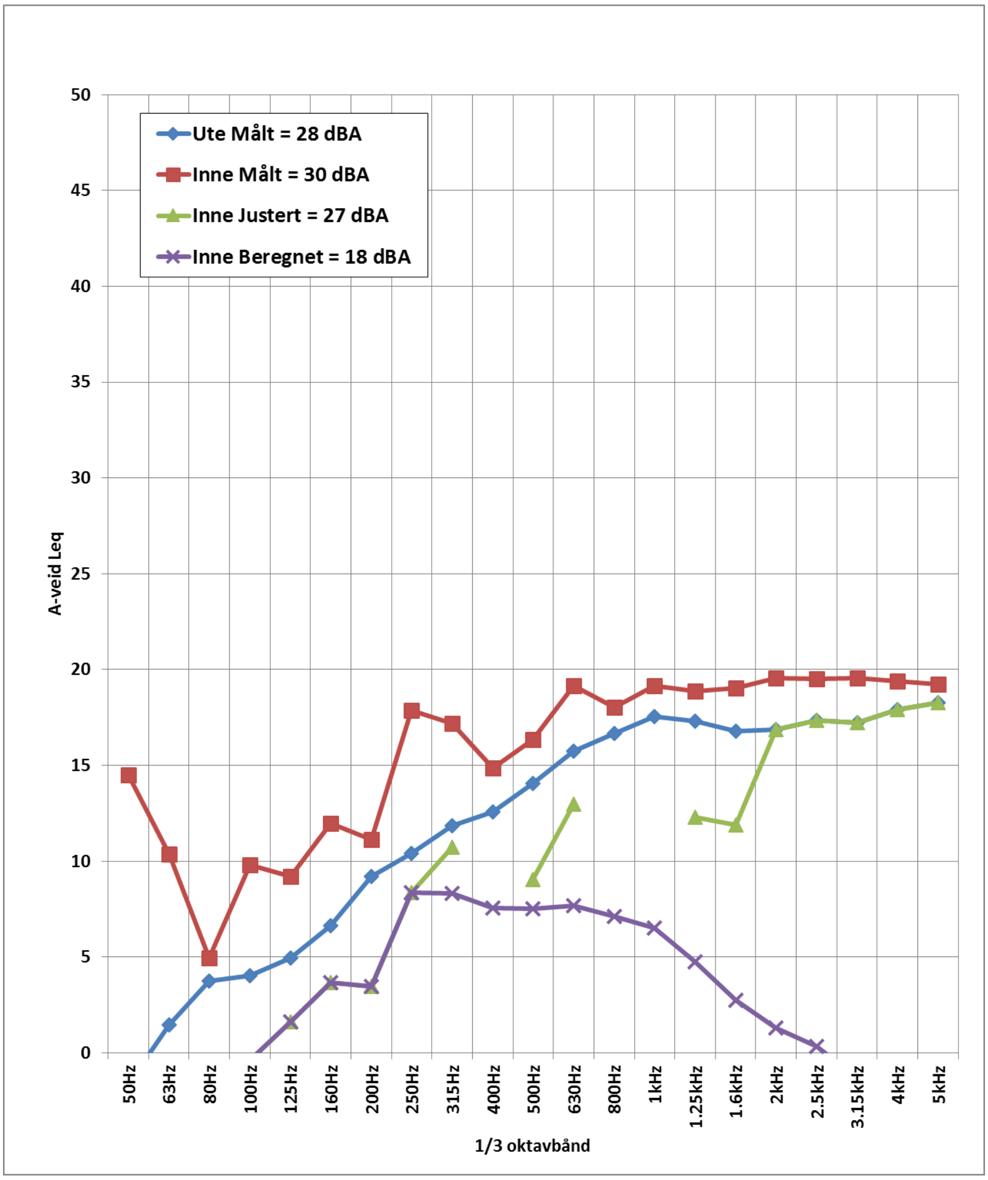
Location 6 – Day-time



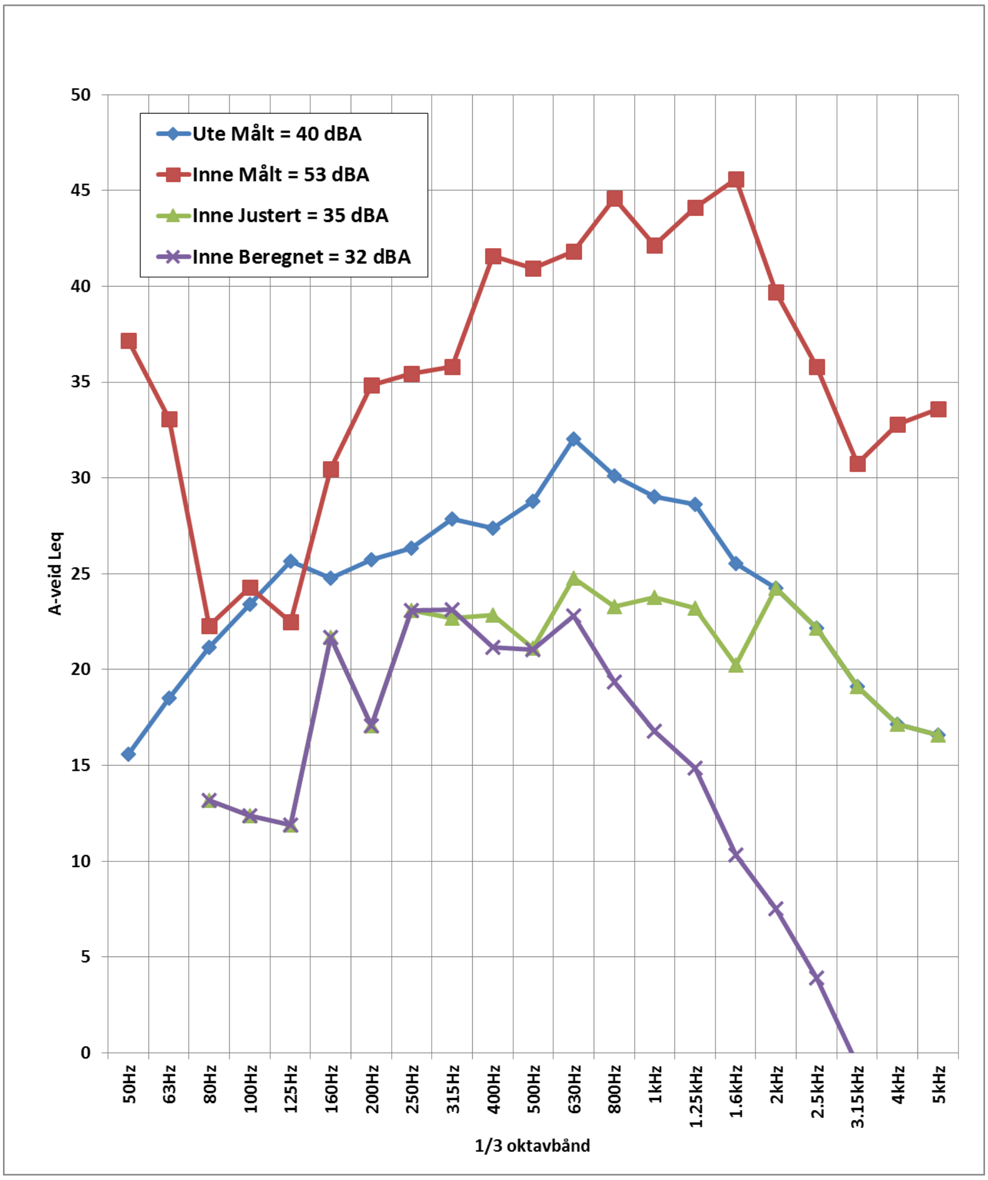
Location 6 – Night-time



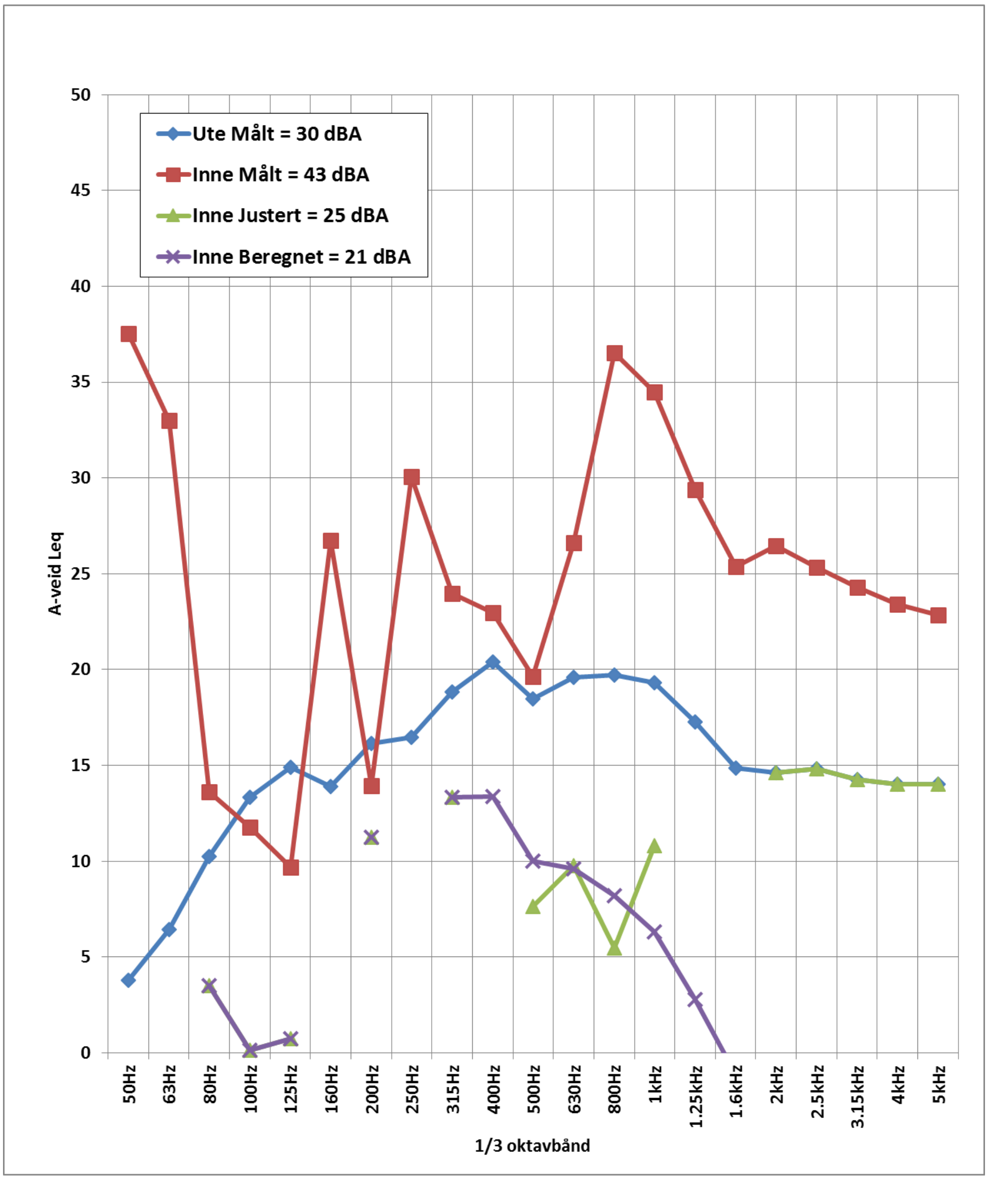
Location 7 – Day-time



Location 7 – Night-time



Location 8 – Evening



Location 8 – Night-time

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