Methods for the Calculation of Sound Propagation

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Introduction

The development of methods to calculate sound propagation has become an enormous push by the noise mapping activities following the requirements of the European directive. Many experts discuss the need of more accurate predictions, but neglect in many cases the decrease of precision that may be the consequence of more and more detailed input parameters.

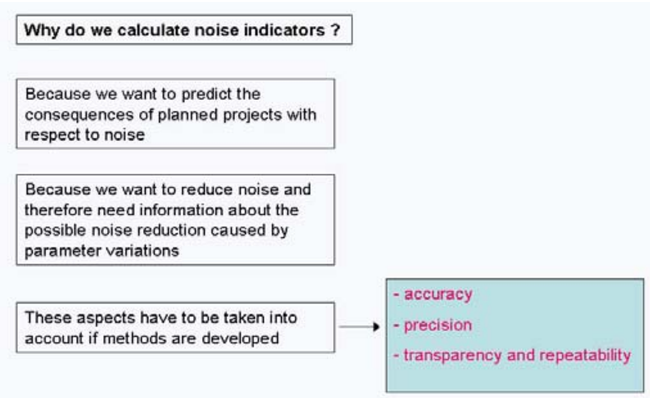

Figure 1 Aspects that influence the selection of methods

These aspects of accuracy and precision can be explained with example figure 2.

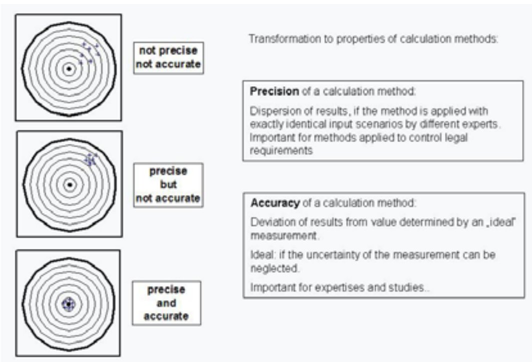

Figure 2 Accuracy and precision

If the shots deviate from the center and are distributed, the method is unprecise and inaccurate. If the dispersion is small, but beside the target, the method is precise but not accurate. Standardisation of methods is a way to improve the precision. More complex and scientific methods may be more accurate, but they offer many screws to adjust the result – different persons will get different results.

In that sense the engineering method ISO 9613-2 is a relatively precise and transparent method. If the sound pressure level at a receiver is calculated from the sound power level, the step by step results are clearly defined and can be combined even with a pocket calculator.

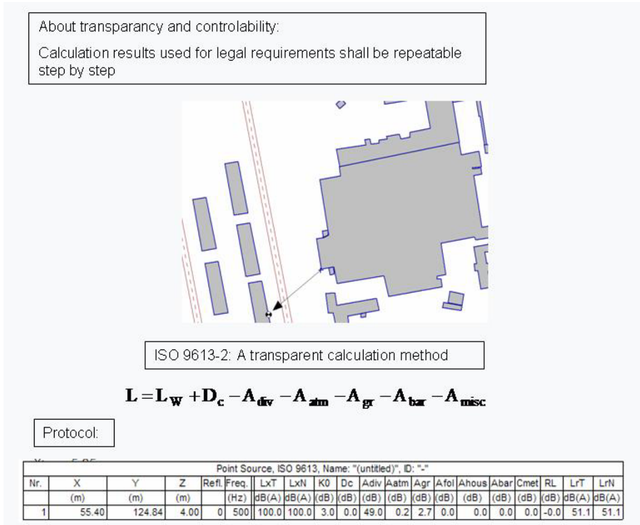

Figure 3 ISO 9613-2: transparent and high precision

In physical reality many different phenomena may influence the sound level measured in larger distances from a source. These effects are source radiation (sound power frequency spectrum, directivity), small scale propagation (reflection, screening, absorption) and large scale propagation (air absorption, ground reflections, wind and temperature, turbulences).

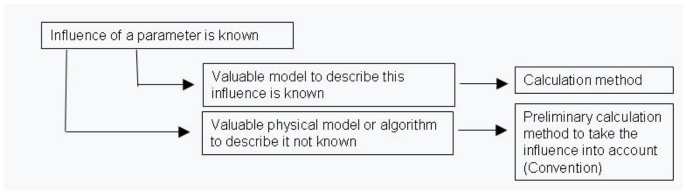

Figure 4 Methods to include physical phenomena

In practice most of the models used are well known since many years. Unfortunately more and more calculation models are developed that are nothing else but a new combination of such well known procedures.

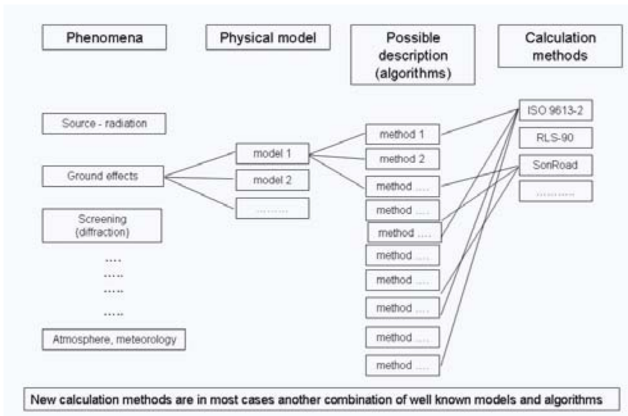

Figure 5 How phenomena are taken into account in methods

Scientifically based models

Figure 6 gives an overview to more or less scientific based methods, that are based on approximate solutions of the wave equation or on a simulation of the particle movements by separating the medium in small volume elements.

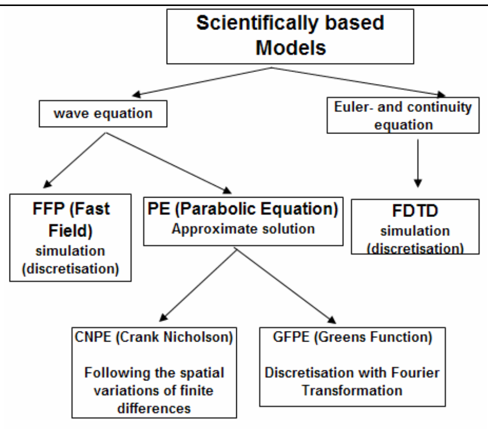

Figure 6: Scientifically based methods

These methods are generally used to investigate special problems in detail, but are in most cases too complex and therefore time consuming to be used for prediction of noise levels with complex scenarios. The influence of layered atmosphere on large scale propagation or the diffraction around a complex object are typical tasks where such methods can – or even must – be applied, but they cannot be used to calculate the noise distribution in a city or the level caused by an industrial facility with complex technical sources at residential areas nearby.

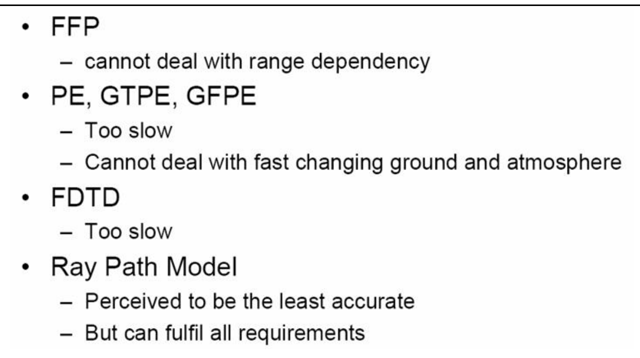

Figure 7 Assessment about some scientifically based models (Y.W.Lam, Acoustics Research Centre, at “The Future of Computational Acoustics, London, Feb. 2007)

But what can be done is to use these methods to study the influence and the consequences of special parameter combinations and to transform the relations found to better applicable empirical algorithms.

Engineering models

For such problems engineering models are used, that are based on the calculation of rays or particle tracks representing the sound propagation from sources to the receiver. Figure 8 shows an attempt to classify these procedures and even well known software packages that can be applied.

If pros and cons are discussed, the phenomena that influence sound propagation must be taken into account.. It is well known that sound propagation is influenced by the vertical temperature profile, but neglecting this influence in RLS-90 must not give less accurate results if sound levels caused by road traffic are determined at the nearby facades. This is one of the main problems in the development of new calculation methods – to find a justified balance and not to increase the complexity without benefits in the end results.

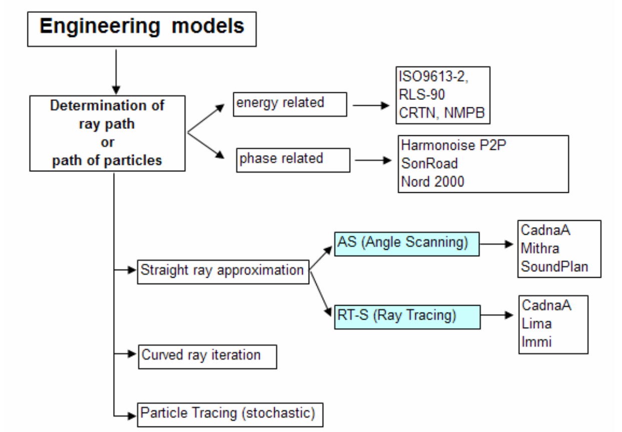

Figure 8: Engineering models.

The importance of physical phenomena influencing sound propagation depend on the task or the specific application. If a certain phenomena is not taken into account with a given calculation method it is always possible to construct a scenario where errors of 10 dB and more are produced neglecting this special influence. Therefore it is necessary to define the range of application and to study thoroughly the priorities before a method is created or modified. More complexity needs more detailed input information and reduces transparency and the possibility to validate the calculation.

Calculation methods used to control legal requirements should be very precise – different experts should get the same results with a given problem. Precision may even be more important than accuracy in such cases.

For detailed analysis of noise problems with road traffic, railway noise and industrial noise the type of source radiation, ground effects, diffraction around objects and reflections – all this many times and in combination between source and receiver – have to be taken into account.

The existing models used to control legal requirements like RLS-90, Schall03 and ISO 9613-2 are all based on energetic superposition of incoherent sounds – interference effects are not included (even if ISO 9613-2 includes some expressions to comprehend ground reflection with direct sound in a phase related manner). This simplifies the calculation, but may cause some deviations of calculated from measured levels in frequency bands if only few correlated sources radiate or with a source and a single reflecting surface nearby. With the newer models Harmonoise, Nord 2000 and SonRoad such phase relations are taken into account.

The first mentioned engineering models use basically straight rays to connect sources – and mirror sources – with receivers. Nevertheless bended rays around upper and lateral edges of barriers can be taken into account. To find the possible ray paths two main software strategies are used. These two main principles are shown in figure 3 and 4.

With the mostly used ray tracing technique all sources and mirror sources are connected with the receiver by straight ray paths. Extended sources can be subdivided in smaller elements using the projection method, where the gaps between objects are exactly taken into account, as it is shown in figure 3. Another method is to draw rays subdividing the full 360° around the receiver in constant angle segments and to search for sources in all these segments.

Both methods have their pros and cons, and in the following only the most important differences shall be mentioned.

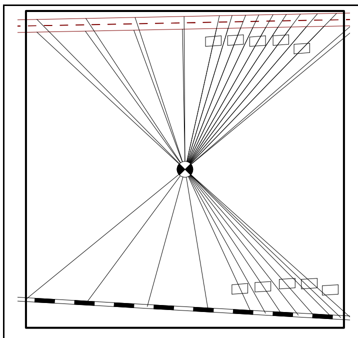

Figure 9 Road and railway calculated with RT-D

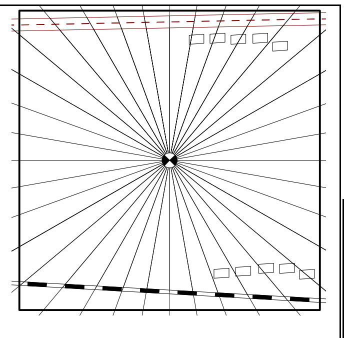

Figure 10 Road and railway calculated with AS

In the framework of noise mapping the calculation times are relevant and such calculations need always a balancing of accuracy and time expenditure. Reflection calculation – especially to find the relevant mirror source positions – is extremely time consuming, and therefore only the important reflectors near the sources and near the receivers can be taken into account. With RT methods it is possible to restrict the reflection calculation to a definable maximal distance from source and receivers. With AS methods this is only possible with respect to receivers. With a parameter setting "reflection depth" the splitting up of a search ray all the times an object is crossed must be restricted to very few objects – reflections near sources far away can not be found automatically.

The advantage of AS methods is a very quick reflection calculation in spaces without objects that are surrounded by reflecting objects– this is the case if the level caused by a road canyon with facades at both sides has to be calculated at these facades. Using a small reflection depth of 0 or 1 makes it possible to calculate even up to high orders in acceptable times. But the price is that even important reflectors near sources far away are not detected without manual access.

RT is the more precise method if gaps between screening objects and complex sources are included. The detection of screened and unscreened part of the sound energy reaching the receiver is very precise if the projection method is applied, as it is shown in figure 11.

The first step in the calculation of noise from extended sources like roads is to construct straight lines connecting the receiver with the outmost edges of all objects between receiver and source – these lines are used to subdivide the extended source in screened and unscreened parts.

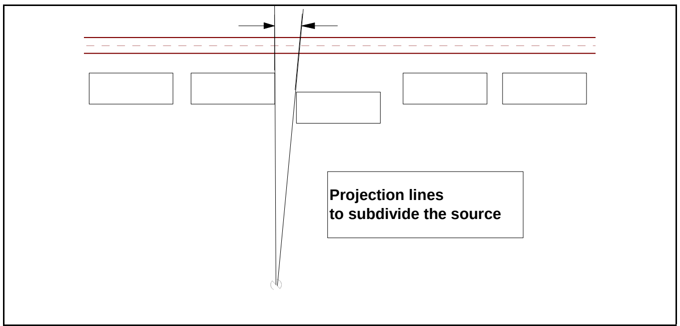

Figure 11 Projection lines to subdivide extended sources

If projection is not used, errors of 10 dB and more can occur, if the receiver is behind such a gap. Figure 12 demonstrates the reason – in figure 12a no projection method is applied and the rays are only subdivided according to the distance criteria. All rays (that are generally not seen by the user during calculation) are screened and the level is 40.5 dB(A).

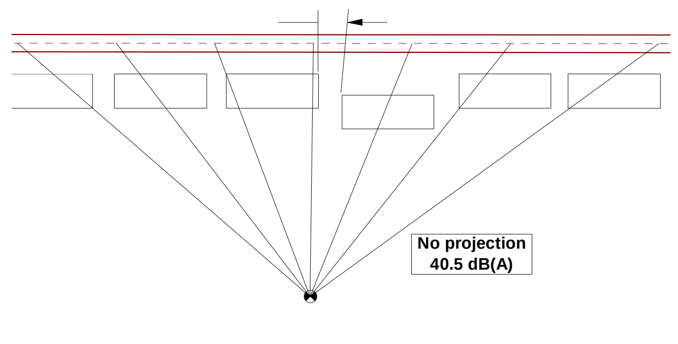

Figure 12a No projection applied – subdivision of road only according to distance criteria

If projection method is applied, the calculation ray through the gap represents exactly the sound energy passing without diffraction.

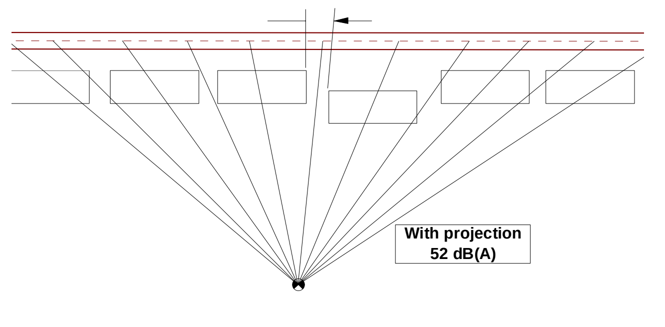

Figure 12b Projection applied – the gap is exactly encountered a level of 52 dB(A) is calculated

The calculation behind facades with gaps is obviously not reliable – the deviations of about 12 dB are unacceptable for most cases.

If noise maps are calculated, the cases where a gap is crossed by a calculation ray without projection are randomly distri-buted and even if it is the case the calculated sound level has nothing to do with the length of the relevant piece of road. The same with AS method – if the distance of adjacent rays is larger than the gap the results fluctuate from grid point to grid point. This can be seen with the noise maps presented in figures 13, 14 and 15.

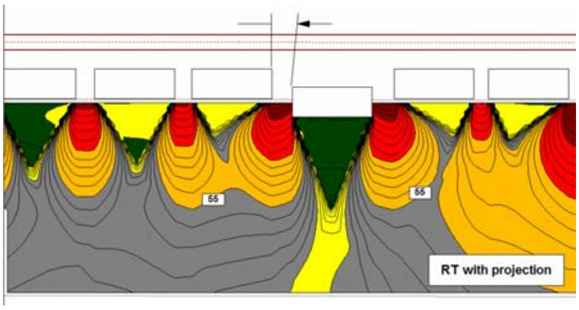

Figure 13 Calculation with RT an projection active

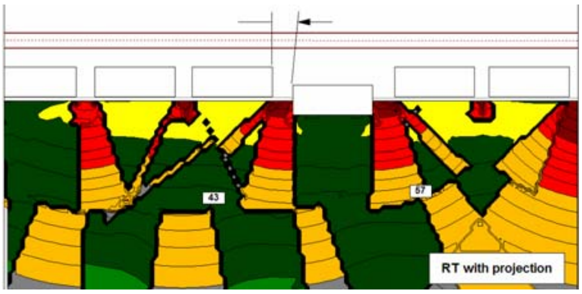

Figure 14 Calculation with RT – projection inactive

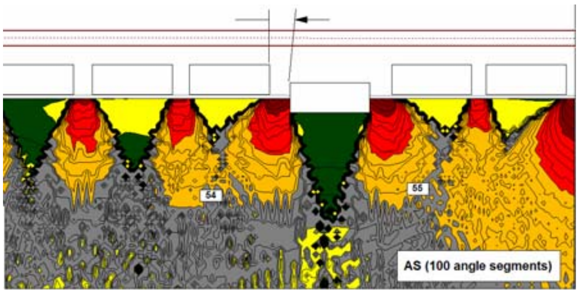

Figure 15 Calculation with AS – 100 angle segments of 3,6° each

This examples show, that application of projection with RT method – or very small angle segments with AS method – is absolutely necessary to get acceptable accuracies.

The same is the case with reflected sound. Figure 16 shows that it is not sufficient to subdivide the road and to apply the mirror method for the subparts. The extension of the complete façade must be taken into account, because all the sound energy radiated from the indicated (red) part

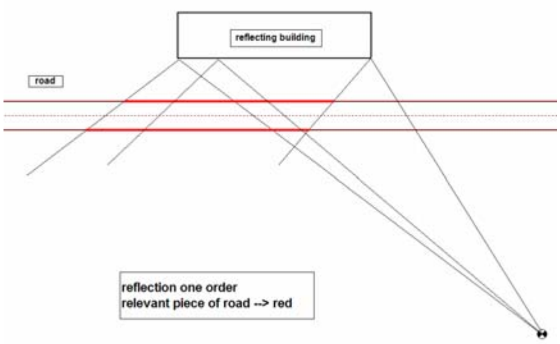

Figure 16 RT: Projection of reflecting objects

Unfortunately this is not the end of the game – quite often other objects separate the reflected cone into a part that is screened and another part propagating free. Therefore all objects must be included in the projection method to find the relevant subpartitions of the source.

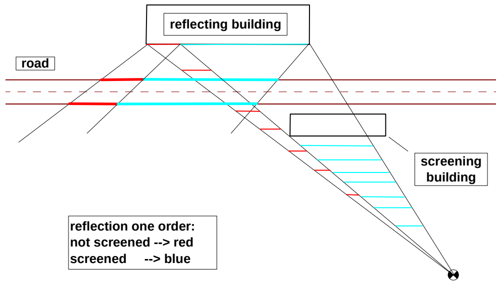

Figure 17 RT: Projection of reflecting and screening objects

These discussed methods are purely geometric and needed to find the ray cones that must be treated separately if extended sources like roads and railways have to be included. This geometric pre-processing is the part of a noise map calculation that needs the largest part of the calculation time. It is independent from the calculation method applied (RLS-90, ISO 9613-2 or even Harmonoise engineering method), because this method has to be used for each ray separately afterwards. Only some very oldfashioned standards like CRTN don't use the geometrical possible reflections, but add a constant correction if a reflector is crossed by the ray.

If meteorologic influences shall be taken into account more precisely, it is necessary to model the atmosphere with spatial varying properties. Two principally different strategies are indicated in figure 8. Generally a layered atmosphere with vertical – and even varying - gradients of temperature and wind speed is used to get the vertical sound speed profile. With such conditions the sound rays may be curved downwards or upwards as it is shown in figure 18.

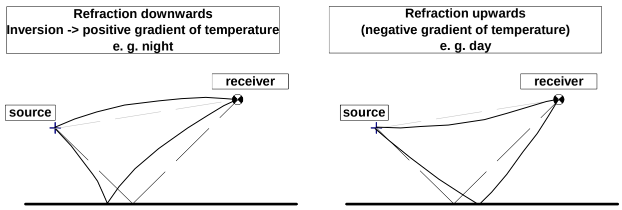

Figure 18 Bended rays – a consequence of sound speed variations with height

In such cases the possible ray path can be constructed step by step in an iterative process. The geometric attenuation is calculated from the spreading of two rays at the receiver position related to the angle between them at the source. Another method – indicated in figure 8 - is to construct the path of particles radiated from the source in directions that are randomly distributed. The energy at the receiver is determined by summing up the number of particles crossing a small control volume.

The advantage of these two last mentioned methods is the inclusion of meteorological influences, but this is payed with a lot of problems that are important in smaller scales like the subdivision of extended sources with neighboured objects , screening in combination with reflection and others.

These and a lot of other aspects have to be taken into account if strategies and methods are developed. The physical model to simulate reality is one side of the coin – the other side is the strategy to force a computer to organize this job with a given project in the best way. The two aspects are not independent and therefore a cooperation of acousticians and experts in software techniques is the best condition to solve such problems .

It depends on the type of problem that has to be tackled what is more important - very detailed calculations in small scales or neglecting these small scale influences of objects and taking into account long range meteorological effects.

In noise mapping according to the EC Directive about environmental noise we want to know how many people are exposed with given noise levels. The levels are calculated around the facades of residential buildings and the largest value is used to qualify the exposure of the residents. It is interesting to know if sources far away from a receiver influence the result.

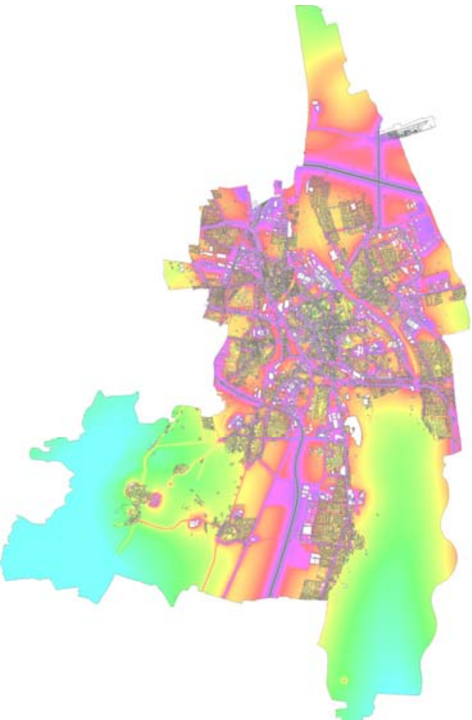

Figure 19 Noise map of Augsburg

Figure 18 shows a noise map of the city of Augsburg – the model includes about 80000 buildings and all main roads. To get an impression of the influence of large scale calculations the façade levels have been calculated using only ray paths up to a defined maximum length of X m. The result was the number of persons that are exposed to levels Lden above 65 dB. The calculation for the complete city was repeated with a maximum ray length of 50, 100, 200, 300 and 500 m. The evaluation of the number of people exposed above 65 dB(A) is shown in figure 20.

The diagram shows that the large distances, where meteorological effects come into play, are not very important. The result does not increase significantly if the radius is increased above 300 m.

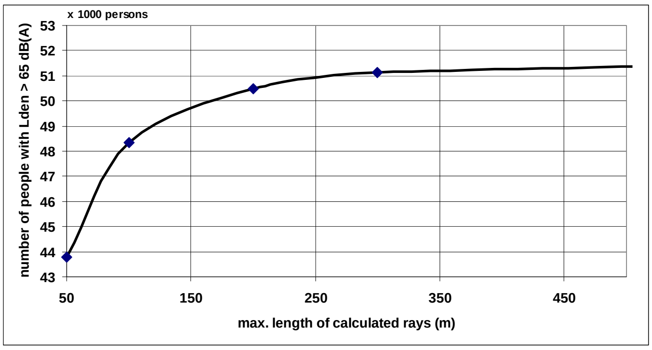

Figure 20 Recalculation of the façade levels with maximal length of rays and evaluation of number of exposed with Lden > 65 dB

Therefore it may be of limited value to spend a lot of effort to include long range meteorological effects but to loose precision and accuracy in the very important short range propagation.

In some publications and standards more scientifically based methods are used as “reference methods” that shall be used to “calibrate” the engineering models. Such approaches are only acceptable if the uncertainty of these reference models has been proven to be superior by comparison of calculated and measured results. And even such comparisons are only reliable if first the calculation is performed by one group and then the measurements are made by another group. Scientifically based models may be helpful to study the physical models in detail – but what we need to include all the influencing phenomena in our predictions are engineering models with acceptable accuracy, precision and transparency.