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MODELING ACOUSTICS AS A POWERFUL DESIGN TOOL FOR OPEN PLAN OFFICES

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ABSTRACT

In the Netherlands, many companies have already changed their traditional ways of working into a more modern working concept, so called New Work or Work New Style (Het Nieuwe Werken). In 2011 the ‘Handbook Building Physics Quality’ (BKK) for Offices was released by the Dutch Government Building Agency (Rgd) in cooperation with leading Dutch consultancies. In the Handbook acoustical parameters are given for designing an open plan office with different types of working places with a satisfactory level of acoustical comfort. These new acoustical parameters are based on the ISO 3382-3:2012 norm and were very recently implemented into acoustic modeling procedures. From 2012 on, acoustic modeling can also be used to design open plan offices based on the new acoustic parameters. Acoustic modeling has proven to be a strong tool of communication to architects, facility managers and even furniture suppliers in order to create a satisfactory level of acoustical comfort. In this paper some examples of the professional working field are given about how the design process has been influenced by using acoustic modeling.

INTRODUCTION

The so called New Work or Work New Style/WNS (in Dutch: Het Nieuwe Werken/HNW) is based on a more flexible way of working. One can not only work in the office, as being the actual office building, but one can also work in many other spaces, like a café or at home in a more familiar environment. Because of the modern more flexible way of working, the office building is no longer a traditional office with a fixed office lay-out. Fixed working spaces are traded in for inspirational interactive meeting spaces, silent concentration cells, individual working spaces and many more creative spaces. These are all arranged in in one open space, if possible. The office is designed as a meeting point and is meant to be more than a working space. Many diverse working spaces in one open space are a real risk to disturbance of concentration and by that a negative influence to productivity. The main sources of disturbance are sounds produced by colleagues, like talking, telephoning and equipment like printer corners and coffee corners. Sound and noise are invisible parameters and because of this it is often hard to convince the builder and contractor of the necessity of acoustical measures.

Before 2012, it was acoustically not common to rate or design the achieved comfort in open plan offices by any other parameters except for the reverberation time (T in seconds) and the background noise level. In new office environments new challenges are found in:

- complex geometry with large, relatively low areas and unevenly distributed sound absorption
- describing the individual and overall acoustics in new parameters based on specific demands like the ability to concentrate in open plan offices

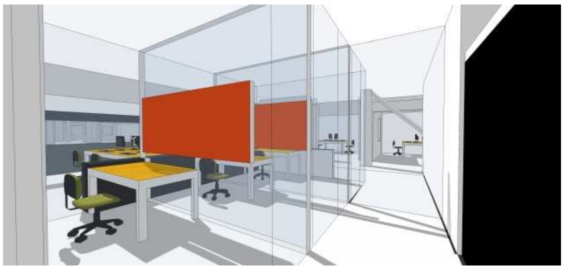

Figure 1 Concentration cells WNS style

Figure 2 Meeting space WNS style

Acoustic modeling was not only found to be a very practical and powerful tool for these two reasons, also modeling acoustical sanctions can be varied in several parameters like different types of measures, the amount of absorption materials and differences can be easily evaluated and discussed thanks to the visual graphics.

To give an insight in the acoustic quality of the personal and overall environment, acoustic comfort can be rated and evaluated based on acoustic modeling. In this paper several cases are presented from practical experience.

LEVELS OF CHANGE

The changes happening in the office environment are a result of changes happening on *macro level, meso level* and *micro level.*

Governmental agencies and many large companies aim on *macro level* at higher goals like reducing the building costs by increasing the levels of occupation in the office. Because of the more flexible ways of working, a proper technical network is, of course, needed and provided. These new tendencies on macro level are, fortunately, nowadays supported by new regulations and norms. On a meso level a better acoustic comfort can be achieved e.g. by soundscaping the open plan office. For example different sound zones can be created based on the needed levels of interaction and concentration. This can result in a particularly noisy zone on side of the building changing gradually into more silent zones at the other side of the building.

On *meso level* agencies and companies can decide to follow the trend of WNS working. This means flexible working stations are needed in great diversity like meeting spaces, silent cells and standard individual working spaces. Often a 'clean desk policy' is combined with the introduction of WNS working, including personal lockers and collective waste bins. This changes the logistical routing in a building. In some cases necessary adjustments can be made in existing buildings, in other cases the existing building no longer 'meets the need'. This means redesigning existing buildings or, even more drastically, designing and building completely new buildings according to the companies wishes in WNS style.

At last, on *micro level*, individual working spots need to be part of an attractive and inspirational working environment in which sufficient acoustic comfort is offered. At this level of design, acoustical measures like the choice of materials for walls and ceilings walls and ceilings, interior elements like floor covering, chairs, tables, screens, closets and room dividers are good options.

ACOUSTICS AND MODELING

For simple, diffuse rooms, the reverberation time can be easily calculated using Sabine's formula based on the total volume and the total absorption. In new office environments with its large, relatively low areas and unevenly distributed sound absorption this formula is not applicable. However, the formula can be used for a quick first impression.

The norm NEN-12354-6 (annex D) provides a more advanced method for calculating the reverberation time in non-diffuse rooms with unevenly distributed sound absorption. With this method the reverberation time T first can be calculated in three dimensions T_x, T_y, T_z and subsequently converted into one value T. This method only works for a simple shoebox-shaped room. For rooms with a more complex geometry or sound blocking interior elements, like closets or room dividers, this method is also able to give a realistic prediction of the acoustics.

The ISO 3382-3:2012 norm provides some newly introduced parameters, like the distraction distance r_D, privacy distance r_P and the spatial decay rate of speech $D_{2,S}$ in order to achieve some kind of rating for the acoustic comfort in open plan offices.

The Dutch Handbook Building Physics Quality for Offices (BKK), released in 2011, already contained some of these new parameters based on the draft norm ISO 3382-3:2009 and is already used as such.

Because of the more complex need in formulas and geometry more advanced formulas or computational models are needed. The modern ray-tracing computer model is able to calculate the new acoustic parameters for the complex geometry of an open plan office. An acoustic model based on ray-tracing is a model with a closed volume based on the geometry points of the space or room, surfaces and surface properties like absorption, reflection and diffusion. Within this volume sound waves are being propagated as rays coming from a sound source and reflected against the surfaces according to their surface characteristics. The path of the waves is calculated based on ray-tracing for simulating the interior acoustics. In the better ray-tracing models, wave propagation is tackled with advanced algorithms mostly for the first reflections. These calculations result in graphics which can be of great use to improve communication between acoustic advisors and architects, facility managers and even furniture suppliers.

The new acoustical parameters based on the norm ISO 3382-3:2012 for measuring room acoustics in open plan offices were recently implemented, not only as measurement parameters, but also as calculation and prediction parameters in acoustic modeling programs like *CATT-acoustic* and *ODEON*. These modeling programs are based on ray-tracing.

Parameters and target values

In acoustic modeling the following parameters can be used with given target values.

The *reverberation time* T in an open plan office should not exceed 0,5 seconds. This value relates to furnished open plan office spaces.

The distraction distance and privacy distance are based on the *speech transmission index* STI. The STI index represents the transmission quality of speech with respect to intelligibility. In a conference setting a high level of intelligibility is good, in an open plan office a high level of intelligibility is undesirable. Cognitively demanding tasks are carried out with a higher error rate (41%) during exposure to intelligible speech in contrast to exposure to a normal error rate (4%) in perfect silence (Hongisto, 2005). Therefore the STI index is used to support the acoustic design.

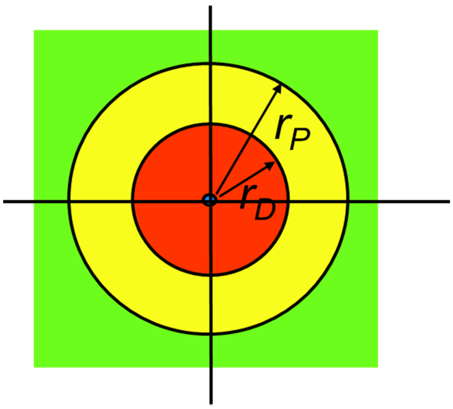

Figure 3 Distraction distance r_D and privacy distance r_P

The *distraction distance* is the distance from a speaker where the STI falls below 0,50. Above this distraction distance concentration and privacy start to improve rapidly. The *privacy distance* is the distance from speaker where the STI falls below 0,20. Above the privacy distance, concentration and privacy are experienced very much the same as between separate office rooms. STI values less than 0,20 are difficult to achieve in open plan offices because of the openness. In figure 3 the principle of distraction distance and privacy distance are illustrated schematically, where red is the zone of 'high distraction', yellow the zone where concentration and privacy start to improve rapidly and green the zone where concentration and privacy are experienced very much the same as privacy between separate office rooms.

The *spatial decay rate of speech* $D_{2,S}$ defines the decay of A-weighted sound pressure level of speech per distance doubling. This distance reduction does not include the background noise level, in contrast to the STI index. Without screens or room divisions, a spatial decay of 3 to 5 dB is attainable in an open plan office. Up to 11 dB can be achieved with large screens or room divisions.

SIMULATION AND EXPERIMENT

Modeling turned out to be a powerful design tool in designing and decision making. As mentioned earlier, sound and noise are invisible parameters. This makes it hard to point out a certain level of acoustical comfort to a contractor, designer or facility manager. In modeling a great advantage is created by connecting graphics and colors with abstract acoustical parameters. For example, the color red stands for danger and a non-acceptable acoustical environment, where the color green expresses a silent and acceptable environment enabling high levels of concentration. Color is a strong communication tool for explaining levels of quality. For three different cases, the impact of modeling in the design process is illustrated: the design of a completely new building, the design of a completely new interior in an existing building and the design of changed elements for an existing interior in an existing building.

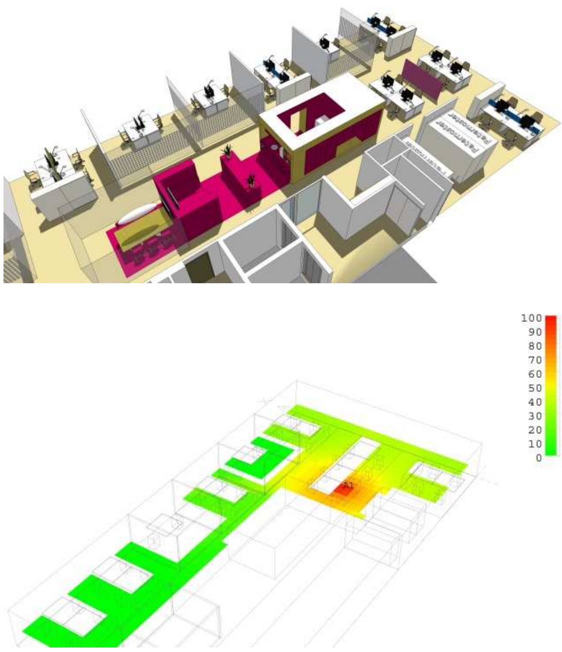

Figure 4 Distraction distance r_D (yellow to orange) and privacy distance r_P (light green to green)

First case: Design new building town hall

A couple of years ago, a new town hall was designed for a Dutch city with up to 40,000 inhabitants. The traditional individual offices of the old town hall were traded in for flexible working spaces in an open plan office according to the WNS. A great diversity of working space was created within a distance of

Figure 5 (re)designing office lay-out

about 10 to 15 meters. With the help of a computer model (figure 4) the sound of a human voice was shown to be of great impact within a reach of at least 10 to 15 meters. The distance of impact, being the *distraction distance* r_D, turned out to be in the same range as de distance of functional diversity. This means the wishes for diversity of functions were not achievable in terms of acoustical comfort.

Together with the architect, the organization advisor and the facility manager a new lay-out of the office floor was designed. The office lay-out was re-designed in a soundscape with louder noise zones and more silent zones. The most noisy functions like meeting rooms and the most silent functions like so called concentration cells were used as isolators in between zones. In figure 5 the ‘before’ and ‘after’ office lay-out is shown, where the upper part shows the ‘before’ and the lower part shows the ‘after’. Nowadays the town hall is in use as a successful implementation of the WNS.

Second case: Designing new interior housing for existing building

Very recently a governmental organization selected a new strategic accommodation for their existing organization in an existing building. In an existing building many choices have already been made. This includes the construction lay-out, the air climate system and the acoustical quality of floors, ceilings, walls and the façade. In order to see if there were any possibilities for the new WNS application many measurements were taken. In the empty office the *spatial decay rate of speech* $D_{2,S}$ was measured to be about 4 dB as shown in figure 6. This meant the acoustic quality, based on the existing ceiling and façade, was a good start for adding interior elements to further improve the acoustic environment.

In the empty building one acoustic compartment was made as a real time mock-up as shown in figure 7. In this mock-up the effect of variable amounts and types of absorbing surface was tested. Based on measurements of the *reverberation time* T, the optimal proportion of acoustic material to air volume in the mock-up compartment was determined.

Figure 6a Measurement $D_{L2,S}$ in existing building

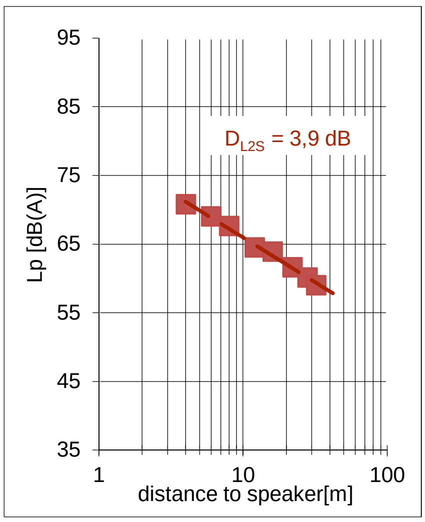

Figure 6b Measurement $D_{L2,S}$ in existing building

Figure 7 Mock-up measurements

Acoustic modeling

A model of a larger part of the office plan was made based on the results of the mock-up measurements, which specified the amount of acoustic materials needed. The office plan is shown in figure 8a, the acoustic model in figure 8b. Per sub-compartment the *reverberation time* T was calculated for specific source and receiver combinations. A sub-compartment is defined as one acoustic environment when situated between walls and high room dividers. The calculation results for one of the source and receiver combinations is shown in figure 9.

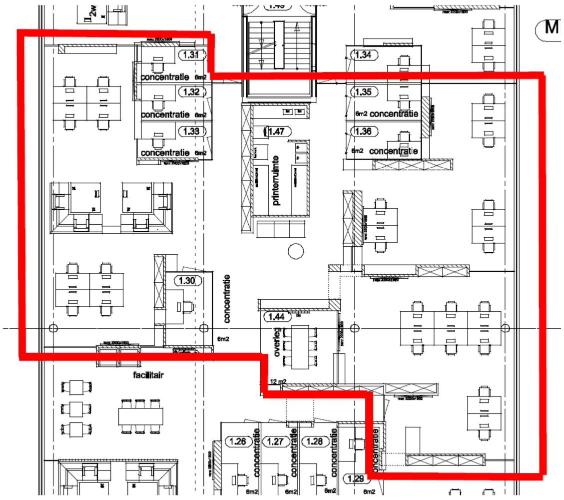

Figure 8a Open plan office lay-out

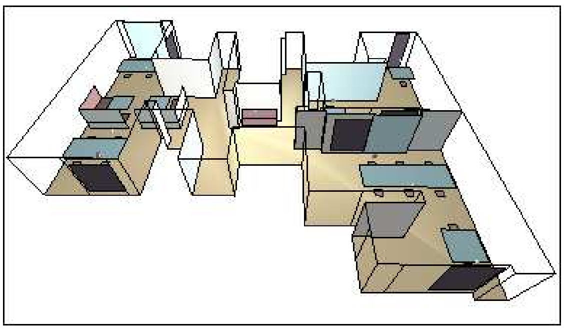

Figure 8b Acoustic modelling open plan office with acoustic absorbing panels (black surfaces)

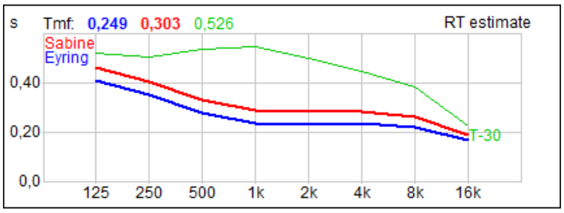

Figure 9 Calculating average reverberation time (upper-line/green line) designing absorbing panels

The upper-line in figure 9 shows the calculated *reverberation time* T to be 0,53 seconds. With this calculation results, the maximum target of a *reverberation time* T of 0,5 seconds is met.

Added value acoustic ray-tracing model

Figure 9 shows the difference between the simple calculation method based on the formula of Sabine and the more complex calculation method of ray-tracing used in this acoustic modeling. In this situation the calculated average *reverberation time* T based on Sabine's formula is about 50% (0,25 seconds) of the actual predicted *reverberation time* T (0,53 seconds). The difference in outcome pleads strongly for using the more complex calculation method of an acoustic model based on ray-tracing instead of using the more simple formula of Sabine.

Third case: Making changes in existing interior design

In another building, also owned by Dutch government, an acoustical problem was detected when clustering 16 working spaces together in one open office space. A clustering of this many working spaces creates a really noisy environment, which makes carrying out complex intellectual tasks nearly impossible. Acoustic modeling was used to show the impact of the application of acoustical measures in this space as shown in figure 10a and 10b, where figure 10a shows the 'before' and 10b the 'after' situation.

One of the acoustic measures meant placing room dividers in between working spaces (limited to 8 persons). These dividers are glass panels with acoustic absorbers at both ends. Another acoustic (and social) measure was turning the interactive lounge benches away from the working spots as seen at the right side of figures 4 and 5. Because of the acoustical measures, a STI-value of 0,50 or lower can be achieved in between the working compartments, which corresponds to the *distraction distance* r_D. By reaching a low STI-value in this particular situation, a large improvement of acoustic conditions was reached. The chance of carrying out complex intellectual activities associated with a 'normal' office job was greatly improved.

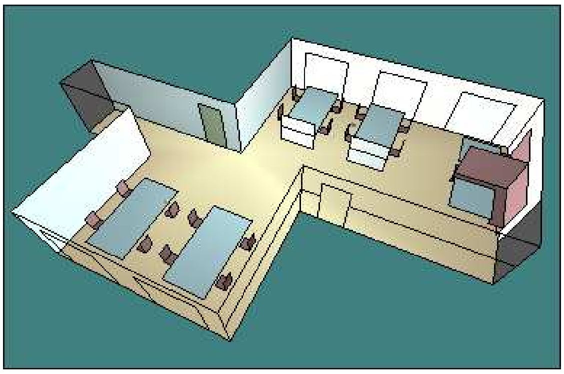

Figure 10a Acoustic modeling, without sanctions

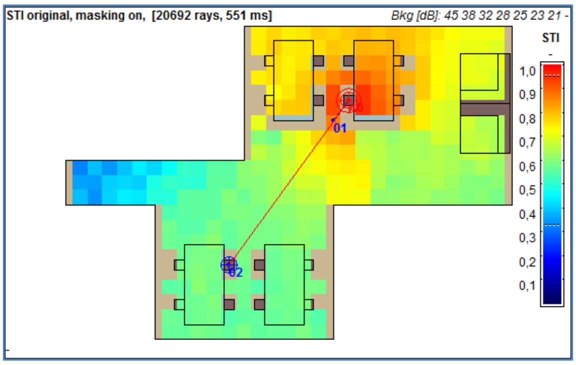

Figure 10b Results acoustic modeling, without sanctions

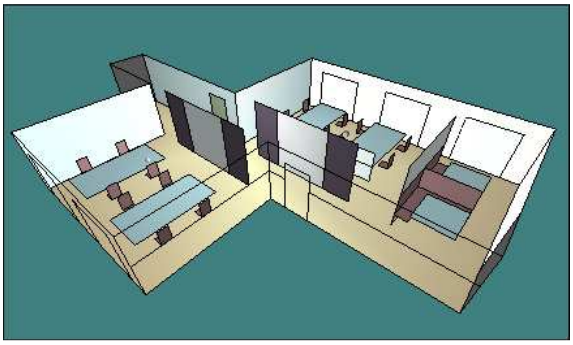

Figure 10c Acoustic modeling, with sanctions

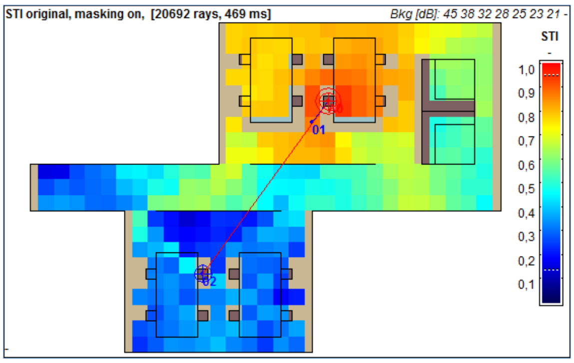

Figure 10d Results acoustic modeling, with sanctions

DISCUSSION AND RESULT ANALYSIS

The results calculated with an acoustical ray-tracing model are very helpful in the designing process. Of course, it should be taken into account that modeling is an approximation of reality. Modeling can be of great use for comparing 'before' and 'after' situations. When interpreting the calculation results, a safety margin should be taken into account.

The safest way to use acoustic modeling, is in combination with measurements to validate the calculation results.

Besides this, an acoustic environment should not only be valued based on technical acoustical parameters. Another important parameter is the individual sensitivity for sound intrusion while doing jobs at high levels of concentration. Another varying factor in valuing the personal acoustic comfort can be found in the actual behavior of co-workers and the corresponding voice levels. Norms and regulations are based on statistics and mean values. It is therefore very important to carefully consider the behavior and the needs of the company, in order to design with sufficient acoustic comfort in mind.

CONCLUSION

For a better insight in the acoustic quality of the personal and overall (work) environment, acoustic comfort quality can be very well rated and evaluated based on acoustic modeling. In this paper several practical cases are given out of the professional environment.

REFERENCES

CATT 2012. CATT-Acoustic™ v9.0c, Gothenburg, Sweden.

Hongisto, V.A. 2005. A model predicting the effect of speech of varying intelligibility on work performance, Indoor Air 15(6) pp. 458-68, Finnish Institute of Occupational Health, Turku, Finland.

International Organization for Standardization 2012. ISO 3382-3 Acoustics – Measurement of room acoustic parameters – Part 3: Open plan offices, Geneva, Switzerland.

Nederlands Normalisatie-Instituut 2004. NEN-EN 12354-6 Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 6: Sound absorption in enclosed spaces, Delft, The Netherlands.

Rijksgebouwendienst et al. 2011. Handboek Bouwfysische Kwaliteit voor Kantoren (BKK), Nederlands Vlaamse Bouwfysica Vereniging, Arnhem, The Netherlands