LIMITING ANNOYING NOISE IN OPEN-PLAN OFFICES

Claus Møller Petersen

Grontmij | Carl Bro
Acoustica – department
Granskoven 8 – DK 2600 Glostrup, Denmark
Claus.Moller.Petersen@Grontmij-carlbro.dk

ABSTRACT

This summer first part of an intervention-project with the purpose of finding better acoustic descriptors than the existing rules on minimum absorbing areas has been finished. Four different companies with eight departments in open-plan offices participated in the project. Beside acoustics also working environment, organization and architectural themes was investigated. Among the main findings were that even though all the offices met the requirement on minimum absorbing areas (0,9 x Floor area), the questionnaires in the same offices showed a certain dissatisfaction with the general acoustic conditions. Measurements and computer simulations (with the ODOEN software) was used to calculate the new ISO 14257 parameters DL_f and DL_2 for all the workplaces. At the present stage of project the DL_f and DL_2 parameters spreads somewhat and shows weak correlation with experienced acoustical conditions between the different workplaces. The same yields for the proposed parameter concerning local acoustic on the individual workplaces. Proposals for interventions have been optimized using the computer models and knowledge from the questionnaires. New measurements and questionnaires will be made after realization of the interventions. Then we shall to see how the changes in acoustical impact will affect the correlation between the objective measured and the subjective experienced acoustical conditions.

1. INTRODUCTION

In 2007 the Acoustica – department at Grontmij | Carl Bro[1] took initiative to the project "Limiting Annoying Noise in Open-plan Offices" that was granted by the Danish Working Environment Research Fund and co-financed by the participating four companies. The companies were from both the public and from the private sector: A town hall, a bank, an architect drawing office and an engineering office.

The project's focus was to investigate the acoustics at the individual work places rather than the average room acoustical conditions. The project has several purposes:

1) to find better acoustic descriptors than the existing rules on minimum absorbing areas
2) to find optimal values for these new acoustic descriptors
3) to be able to calculate the acoustic descriptors using computer simulations and thereby optimize proposals for improving the acoustical conditions and the experienced acoustic
4) to include working environmental/organizational aspects and
5) to include architectural and arrangement considerations in the offices.

[1] The other participants in the project is JJW architects, Acoustic Technology from the Danish Technical University and Department for Working Environment at Grontmij | Carl Bro

1.1. The background

Some of the background for this project has been the many cases where the requirements from the Danish Working Environment Authority to average values of the room acoustical parameters *Reverberation time* or *Total absorption area* was fulfilled while the workers satisfaction was not that good. In some cases you - because of architectural reasons - experience rooms with a dead and a more live end although the average value is fulfilled. This gives to much variation in the acoustic environment and thereby in the workers satisfaction.

Other background comes from work with acoustics in rooms for musical performance. In such rooms it is clear that the placement of absorbers and reflectors is very important to achieve good acoustic conditions, good support and to avoid defects such as flutter echoes and undampened Eigen modes. In spite of this the main stream office arrangement uses only absorbing ceilings and all the rest of the surfaces are hard: The floors, walls often with a lot of glass and the furniture.

1.2. Early investigations - ISO/NP 3382-3 and ISO 14257

A couple of rooms opened our eyes and ears for the importance of a more detailed investigation of the acoustic conditions on individual workplaces. In one of these rooms measurement of the sound propagation showed high DL_2 (rate of spatial decay of sound pressure levels per distance doubling) from one end to the other but low DL_2 from the other end and back. It was in the last propagation direction the noise problem was experienced. By this method it was possible to quantify the importance of even/uneven distribution of the absorbing/reflecting surfaces.

Another (office-) room had two parallel walls, the one diffusing and the other smooth/reflecting. Detailed measurements on sound propagation between workplaces situated along the two different walls showed differences in the DL_f values (the excess of sound pressure level, relative free field condition) depending on placement of the source and receivers. The highest DL_f values typically occurred near the reflecting wall. Also extraordinary high DL_f values showed up in an office placed under a roof with angled hard ceilings. Refurbishment with absorbing tiles solved that problem i.e. gave satisfied office workers and reduced the DL_f values significant more than could be expected by the change in reverberation time. These cases inspired us to investigate office acoustics in a larger scale.

1.3. Hypothesis

One of our hypotheses are that high DL_2 and low DL_f values gives better acoustic conditions and better satisfaction with the acoustic conditions, see [1] and [2]. Another hypothesis is that it must be possible to define an acoustic descriptor that correlates well with the experienced local acoustics on the individual workplaces.

2. THE PROCEDURE

The procedure on each office was to make interviews, fill in questionnaires, do physical registration, acoustic measurements and modeling and at last statistical analysis on questionnaires and acoustic parameters.

In total 140 persons from the companies responded in the questionnaire, corresponding to approximately 55% response.

2.1. The interviews

Interviews were made with representatives from the workers, the management and the working environment organization to target the questionnaire and get information on the specific job functions at each office/department.

2.2. The questionnaire

The questionnaire consisted on both traditional and more specific acoustical questions.

The traditional questions was about name, specific workplace in office, age, sex, hearing, time at this job in open-plan office and average time at the workplace per week. Also general questions – on a 5 point answering scale - on experience with the room acoustics (soft/hard), the noise level (low/high) and the general satisfaction with the sound conditions (satisfied/dissatisfied) were included.

The detailed and more specific acoustical questions were about the individual audible sound sources, inclusive a map of the office where the sound sources with arrows could be marked and described as disturbing speech, not disturbing speech and mechanical sound sources. For each sound source you should describe to which degree it disturbs you, how often it appears and if the source includes speak also how understandable this was. You were also asked to draw a curve on the map marking the border between colleagues which speak you could and could not understand. Beside these detailed questions on the annoying aspects there were also questions on the positive influence of the sound (the "private" zone). The questionnaire further asked about the part of cognitive work during the week. Finally there were questions about eight of the existing countermeasures that were available/important for the workers (to compensate the acoustics in special situations). These questions could be about possibilities for making personal phone calls in separate meeting rooms, occasionally work in separate rooms and exchange on special duties with colleagues.

2.3. The physical registration

The physical registration should be so detailed that it could form the basis for the acoustic modeling i.e. both the room surfaces including surface characteristics (absorption and scatter coefficients) and the furniture at the individual workplaces. During the registration notes on the arrangement and architectural themes were taken.

2.4. The acoustic measurements

The acoustic measurements were performed according to ISO/NP 3382-3 with omnidirectonal source and microphone, with broadband pink noise as signal and source and receiver height 1,2 m. There were performed measurements of reverberation time, background noise, speech level, STI (Speech Transmission Index, see [4]), sound propagation and a lot of individual transmission measurements between workplaces.

3. RESULTS FROM THE QUESTIONNAIRES AND THE PHYSICAL REGISTRATION

The average age in the companies varies from approximately 40 to 45 years.

The general opinion on the acoustics falls in two different groups. In the following both the results from the questionnaire and for the physical registration is stated.

3.1. The mostly satisfied group

Percentage who evaluates	Evaluation	Office size
50 %	“Soft” acoustics	21 to 27 workplaces,
53 %	“Low” noise level	150 – 300 m^2
63 %	“Satisfied” with the general sound conditions	Ceiling height 3,9 m

Table 1. *Answers from the first – mostly satisfied - group*

A closer investigation of this first group shows that more than 40 % of the office workers are out of office more than one day per week. The part of cognitive work during the week was approximately 80 %. Concerning the countermeasures the single most important type of action is to hold not-planned meetings away from the open-plan office, and this need is precisely fulfilled by the physical arrangement. For all the other seven countermeasures the needs are more than fulfilled by the physical arrangement/working conditions.

A special characteristic is seen in the remarks, for instance “too silent office” which probably is caused by a code of conduct which emphasizes silent behavior. At the time for the investigations the main part of phone calls in one of the offices took place in minor separate meeting rooms.

Looking at the arrow-diagram shows approximately same amount of disturbing and not disturbing arrows and a remarkable high part of technical noise. One single disturbing speech-source was the reception that was in open connection to one of the offices.

3.2. The mostly dissatisfied group

Percentage who evaluates	Evaluation	Office size
32 – 59 %	“Hard” acoustics	41 to 350 workplaces,
68 – 69 %	“High” noise level	850 – 4000 m^2
62 – 79 %	“Dissatisfied” with the general sound conditions	Ceiling height 2,6 – 3,2 m

Table 2. *Answers from the second – mostly dissatisfied - group*

In the second group all the office workers are in the office every day in the week. The part of cognitive work during the week was 85 - 90 %. Concerning the eight countermeasures the single most important type of action is to exchange the on duty job at the counter (where clients comes for personal service), and this need is fulfilled by the working arrangement. In another office in this group the single most important type of action is to hold not-planned meetings away from the open-plan office, that is important for approximately 75 % of the office-workers felt important while it was only present for 50 %. For the other five to six countermeasures the needs are more than fulfilled by the physical arrangement/working conditions. The most mis-matching need was the possibility to work in silence-room that was important for approximately 33 % of the office-workers while it was only present for 6 %. In the other office the most important for approximately 55 % was to work in silence room a need that only was fulfilled for 8 %.

Looking at the arrow-diagram shows many disturbing arrows in certain areas enclosed by hard surfaces (inner walls and moveable office screen walls). Also in this group was a remarkable high part of technical noise. The most disturbing speech-sources were situated along hard reflecting walls. A surprising finding was the moveable office screen walls' absorption coefficient which was only 0,1; this means reflecting screens. In spite of this 70-75 % of the second group describes that the sound has a positive influence and that conversation contributes much/very much to the technical and social support at the office.

A few characteristics from this office group must be mentioned: In the smaller office with low ceiling height many hard surfaces was placed near the workplaces and each office worker has to do a lot of mixed work functions at the same time. In this office the main gangway to the canteen passed through the office resulting in much footstep noise/drum noise from the hard floor and too much irrelevant speech. In the larger office there was more than 50 m between the facades, and thereby minimum outlook. Some daylight came to the office via the nine skylights with hard horizontal surfaces, which on the other hand gave some inexpedient sound reflections. Also the arrangement with (reflecting) office screens and bookcases gave a lot of boxes/courtyards with reflected sound paths and lack of visual sight.

4. ACOUSTIC MEASUREMENTS AND MODELLING

The measurement results are presented in several parts:

1) Total absorption area, A
2) Sound transmission between workplaces
3) Local acoustics on the individual workplaces
4) STI measurements and calculations

4.1. Total absorption area, A

In the first group (the mostly satisfied) the total absorption area was well above/better than the minimum requirements from the Danish Working Environment Authority (0,9 x floor area) and also above or at the recommendation in the new Danish Building Code from 2008 (1,1 x floor area).

In the second group (the mostly dissatisfied) the total absorption area was also well above/better than the minimum requirements from the Danish Working Environment Authority (0,9 x floor area). One of the offices in this group is also above or at the recommendation in the new Danish Building Code from 2008 (1,1 x floor area) and the other office is at or below this new recommendation.

The traditional requirements were fulfilled and the new recommendations nearly fulfilled. These measurement results were used to fine-tune the ODEON computer models.

4.2. Sound transmission between workplaces

Sound transmission measurements between workplaces were also performed to see how much the offices amplified the sound compared to free field conditions.

A result from the first group (the mostly satisfied) is shown below

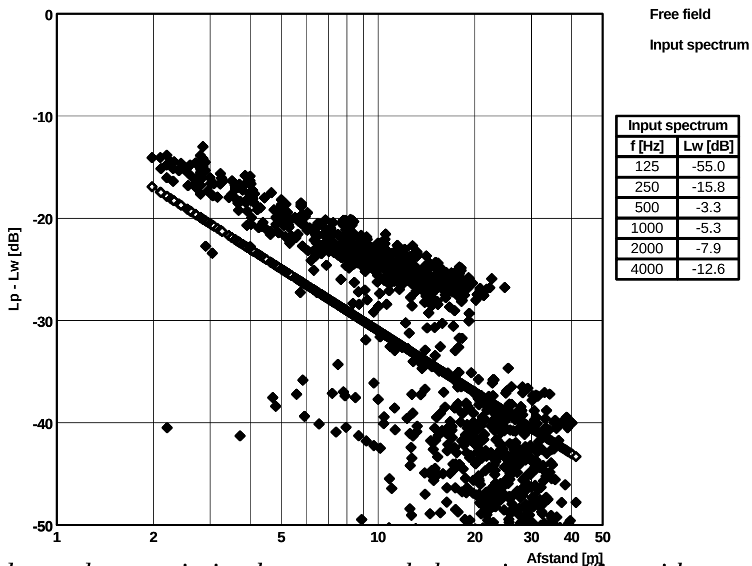

Figure 1. *Simulated sound transmission between workplaces in an office with mostly satisfied workers. The right slant line represents free field conditions.*

The measurement points are separated in two referring to each part of the open-plan office, separated by a door opening. The variation in DL_f from around 4 m to 20 m is +6 to +10 dB and above 20 m from +3 to -13 dB. Typical values for the ISO/NP 3382-3 parameters in middle and far range with speech spectrum are:

Parameters	Value	Distance
DL_{2S}	4,9 dB	4 – 12 m
	11,5 dB	12 – 44 m
DL_{fS}	4,0 dB	4 – 12 m
	-1,4 dB	12 – 44 m

Table 3. *Calculated acoustic parameters in an office with mostly satisfied workers.*

To comparison a result from the second group (the mostly dissatisfied) is shown below

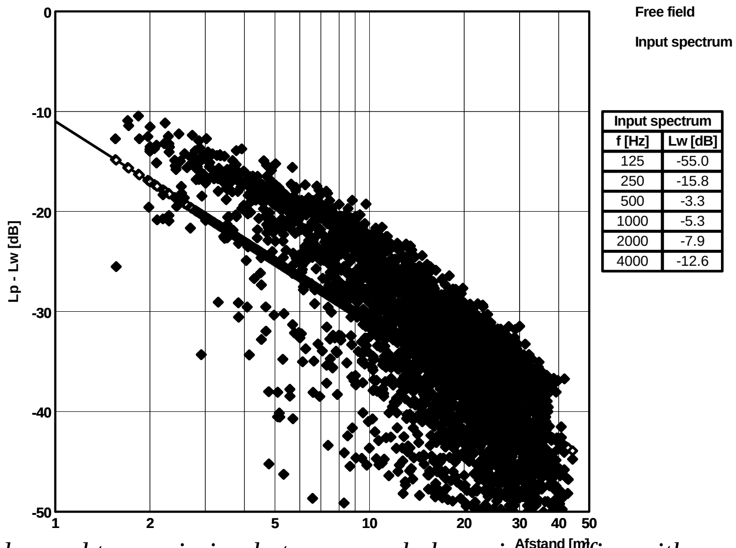

Figure 2. *Simulated sound transmission between workplaces in an office with mostly dissatisfied workers. The right slant line represents free field conditions.*

The measurement point shows mostly an even distribution. The variation in DL_f from around 4 m to 20 m is +8 to +10 dB and above 20 m from +10 to -15 dB. Typical values for the ISO/NP 3382-3 parameters in middle and far range with speech spectrum are:

Parameters	Value	Distance
DL_{2S}	6,6 dB	4 – 12 m
	8,4 dB	12 – 44 m
DL_{fS}	3,3 dB	4 – 12 m
	-0,4 dB	12 – 44 m

Table 4. *Calculated acoustic parameters in an office with mostly dissatisfied workers*

The simulated DL_{2S} values are all near 5 dB or above. According to [1] this is typically seen in “ideally treated rooms” in low-noise workplaces with machinery.

While the hypothesis was that higher DL_{2S} and lower DL_{fS} values would imply better satisfaction with the acoustic environment this is not clear from these two examples or other similar. Comparing table 1 and 2 you see that only the DL_{2S} value in the interval 12-44 m is higher in the mostly satisfied office.

4.3. Local acoustics on the individual workplaces

Trying to describe the local acoustic experience for instance the higher level you feel if you are placed near a hard reflecting surface we used the ODEON software to calculate the ratio between the reflected sound energy and the total sound energy at a point only 20 cm from (above) the source:

$$\text{“}\textit{Nearfield reflection}\text{”} = \frac{E_{2-\infty}}{E_{0-\infty}}(dB)\text{, or in other terms } L_{p,refl.} - L_w + k\ (dB)$$

This parameter is somehow of same type as is known from stage acoustics for instance the

Total support $ST_{total} = \frac{E_{20-1000}}{E_{0-10}} (dB)$, support from the room to the musicians own instrument, or

Early support $ST_{early} = \frac{E_{20-100}}{E_{0-10}} (dB)$, the ease of hearing other members in an orchestra, see [3].

Based on preliminary analysis the simulated average values in the two groups are as follows:

Office workers	Nearfield reflection, average
Mostly satisfied	-13,6 dB
Mostly dissatisfied	-12,8 dB

Table 5. *Calculated acoustic nearfield reflection parameters.*

In this example you see a weak tendency: Low Nearfield reflection seems to give better satisfaction.

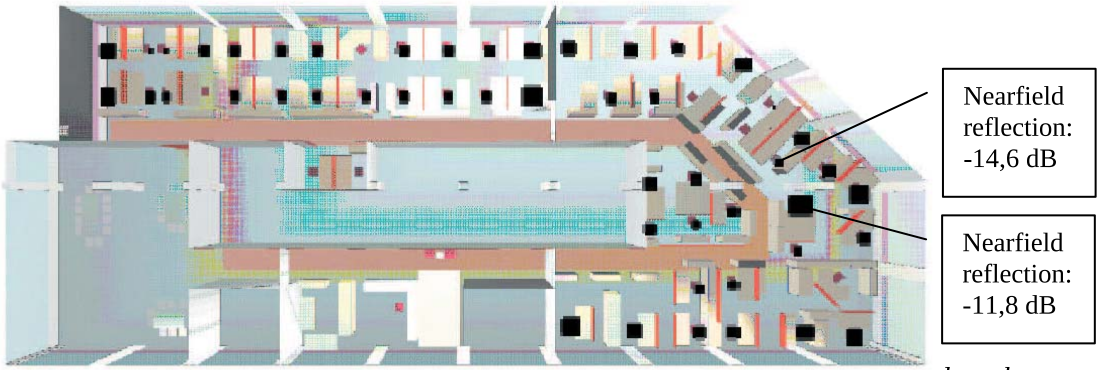

Figure 5. *Example on Nearfield reflections in an office with mostly satisfied workers.*

Inside one group the variation can be more than 10 dB, with the highest values near more hard surfaces.

5. STATISTICAL ANALYSIS

5.1. STI measurements and calculations

In the empty rooms the measured Speech Transmission Index varied from STI = 0,70 to 0,75 in the mostly dissatisfied office group and STI = 0,74 in the mostly satisfied office group. This means that there is no tendency on better satisfaction with lower STI in the empty rooms, which was neither expected in rooms without background noise.

Based on speech level measurements we found that a 40 dBA sound level was an appropriate “live office background level”, close to the 50% percentile level. With this “live office background level” we calculated STI values at all combinations of workplaces – and distances. These data are plotted in the chart below showing the workers specification of the actual workplace is in- or outside his private zone.

The main tendency is that most of the points with high STI values are inside the private zone and most points with low STI values are outside the private zone. There is though a large spread in the data.

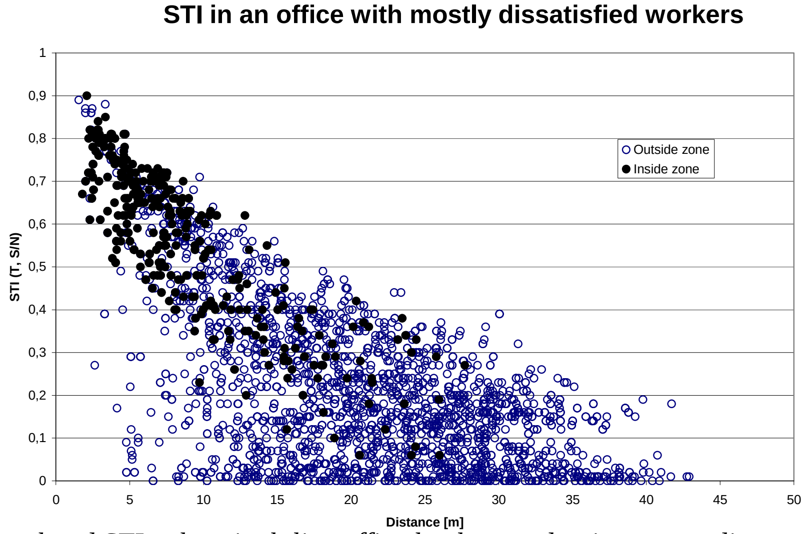

Figure 4. *Simulated STI values incl. live office background noise versus distance in an office with mostly dissatisfied workers. Open circles: Sources placed outsite influence zone. Closed circles: Sources placed insite influence zone.*

5.2. Privacy radius, r_p calculations

Trying to calculate the privacy radius, r_p ref. ISO/NP 3382-3 we then used this chart a used a break-even at STI=0,4 where the statistic frequency of low STI-values inside the private zone equals high STI-values outside the private zone. r_p is a number in meter, in the case below is r_p = 14 m.

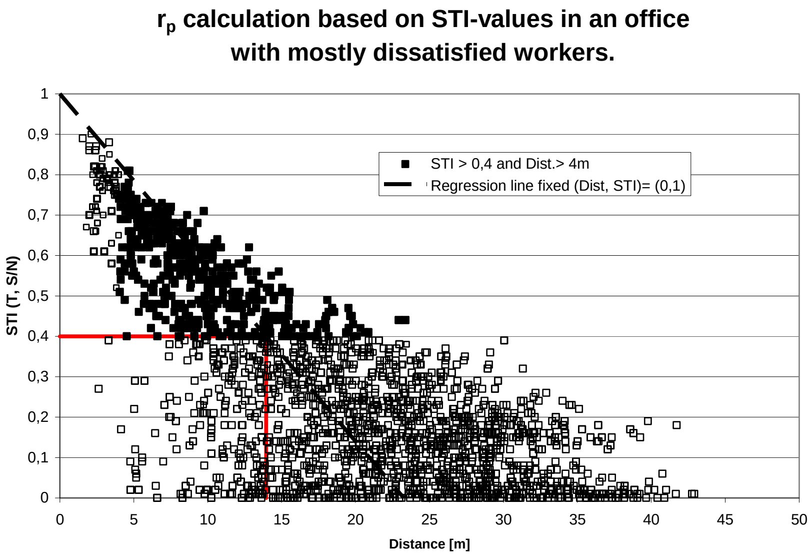

Figure 5. *Privacy radius calculated in an office with mostly dissatisfied workers.* $r_p = 14$ *m*

5.3. Coherence between subjective evaluations

Looking at all the answers on general acoustic questions you find a relatively good coherence in data.

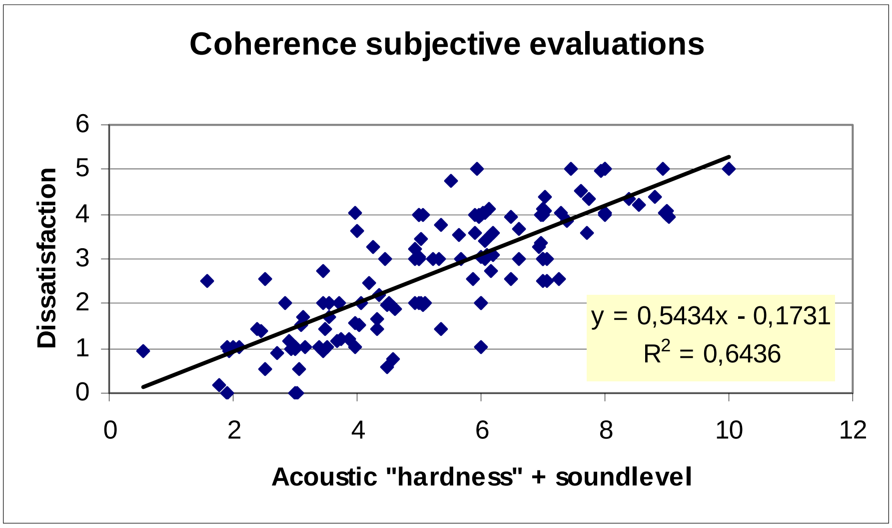

Figure 6. *Coherence between subjective evaluations.*
Interval for subjective scale: 0 – 5 per "parameter"

Another analysis compared the part of cognitive work with the workers "negative" experience (dissatisfaction, acoustic "hardness" and high sound levels). The analysis confirmed other investigations showing that the more cognitive the work is the more sensitive are the office workers on the acoustic conditions.

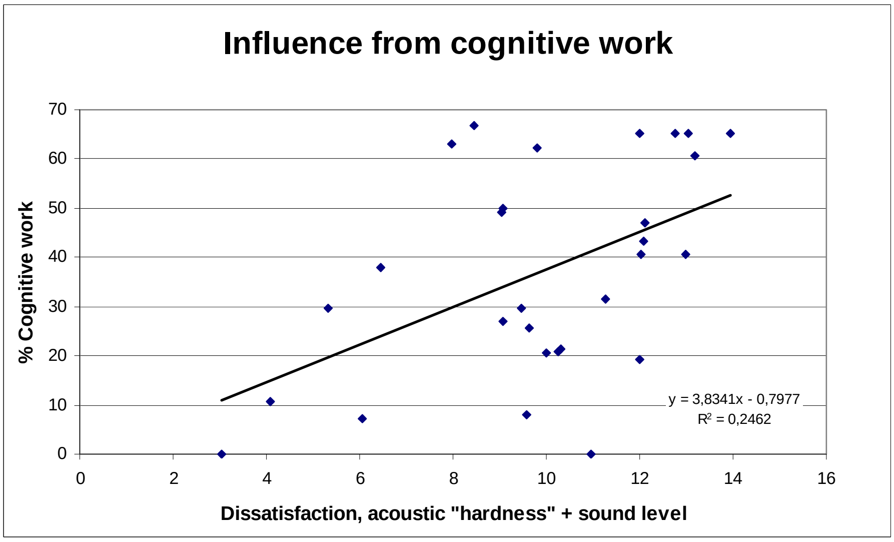

Figure 7. *Influence from cognitive work on general acoustic evaluation.*

5.4. Discussion on DL_f and DL_2 parameters

One of the reasons why the DL_f and DL_2 parameters shows weak correlation with experienced acoustical conditions between the different workplaces may be the fact that the actual background noise is not included in the calculation of these parameters. One other reason may be the fact that the workers at present – before any intervention has been made – do not have any changes in their environment to correlate with their opinion. A last reason could be the very mixed conditions that the workers are situated in – with different job-functions and thereby individual sensitivity on noise and acoustics, plus the fact that also the interfering noise-sources (the "neighbor-colleagues") are different.

6. CONCLUSION

This first part of an intervention project shows that it is not enough to fulfill the general requirement on a minimum total absorbing area to achieve good experienced acoustic conditions in open-plan offices. Though the investigation shows large variation in the subjective experienced acoustic conditions and also in the objective measured acoustic parameters it seems reasonable to conclude that besides the acoustics (A, sound level, DL_f, DL_2, background noise, STI and r_p) the following plays an important role:

- The part of cognitive work
- Countermeasures and time at the desk / the "dose" of office-noise

These parameters, their weight in the total evaluation and also the correlation between the objective and the subjective data-set will be investigated further in the following phases of this project.

7. REFERENCES

[1] ISO 11690-1, Acoustics:1996 - Recommended practice for design of low-noise workplaces containing machinery - Part 1: Noise control strategies.

[2] ISO 14257, Acoustics - Measurement and modeling of spatial sound distribution curves in workrooms for valuation of their acoustical performance

[3] Gade, A.C., Rumakustisk måleteknik, særtryk 14 til kursus 5142. Department of Acoustic Technology, Technical University of Denmark, Lyngby, 1990.

[4] CEI/IEC publication 60268-16 first edition: 1998. Sound system equipment, part 16: Objective rating of speech intelligibility by speech transmission index.