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The cost effects of acoustics in open-plan office

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In the building cost accounting, the considered costs include construction costs, operating costs and life cycle costs. However, the costs due to health effects or decreased productivity due to working in spaces with inappropriate acoustical conditions are usually not included. The solutions for designing open-plan offices acoustically and functionally are well known on basis of research literature. Estimates for decrease in productivity when working in acoustically unfunctional open-plan office have also been suggested in research literature. This can be calculated with the help of speech transmission index STI. In this study, an open-plan office with 170 workstations was studied in two cases: when it was planned to be acoustically functional and when it was planned to meet only the minimum requirements. The construction costs resulting from the acoustical design were determined for both cases. With the use of room acoustic modelling, speech transmission index STI was determined around the office when the sound source was in one of four places at a time. It was assumed, that there is at least one person speaking constantly somewhere in the office. The calculation of the lost working time and finally the resulting costs were based on this assumption. The results show that the construction costs of acoustically functional open-plan office are double compared with the office that meets only the minimum requirements. However, when the costs resulting from the lost working time are taken into account, the acoustically functional open-plan office becomes more affordable in less than one year of time. In five years, the costs resulting from the lost working time are eight times compared to the building costs in the case of open-plan office fulfilling only the minimum requirements and the acoustically practical open-plan office has become significantly more affordable of the two.

1 Introduction

When calculating the costs in construction business, the considered costs include building costs, utilization costs and nowadays to some extent also life cycle costs. However, there are also other costs being generated during the use of a space that are not usually taken into consideration. These include the costs due to health effects or decreased productivity due to working in spaces with inappropriate acoustical conditions.

Acoustics of open-plan offices have been studied considerably worldwide. Based on research literature we know the solutions to design open-plan offices acoustically and functionally well. Also, estimates for loss of working time when working in acoustically unfunctional open-plan office have been suggested in research literature. The decreased productivity can be calculated with the help of speech transmission index STI. Speech transmission index was first developed for evaluating speech intelligibility and acoustic performance of spaces for speaking purpose but it can also be used for evaluating speech annoyance and speech privacy [1, 2].

In this study, an open-plan office with 170 workstations was studied in two cases; when it was planned to be acoustically functional and when it was planned to meet only the minimum requirements. For both cases the building costs resulting from the acoustic design were determined as well as the costs resulting from the loss of working time based on research literature. The results of room acoustic modelling were verified with acoustic measurements carried out according to standard ISO 3382-3 [1]. The study, excluding the performed measurements, is reported in more detail in reference [3].

2 Materials and methods

2.1 Room acoustic computer modelling

The acoustic parameters were determined using commercial room acoustic computer modelling software Odeon Auditorium 14. First, a three-dimensional model was created based on the office geometry which was imported to the room acoustic modeling software. All surfaces were assigned absorption and scattering coefficients in the software. Source and receiver positions were placed in lines according to standard ISO 3382-3 [1] measurement method. Then the software calculated the impulse response from the source position to every receiver position. The model is presented in figure 1.

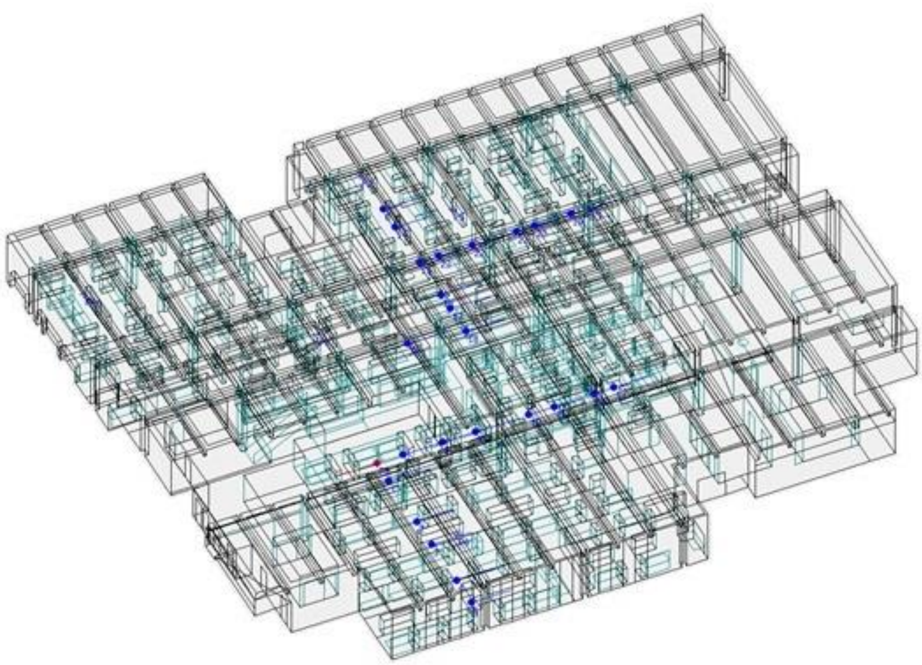

Figure 1: Room acoustic model of the open-plan office. The blue dots form measurement paths.

The equivalent sound level caused by speaking and speech transmission index were calculated at all receiver positions from the impulse response. These values were used to calculate the spatial decay rate $D_{2,S}$, distraction distance r_D and privacy distance r_P accordant with standard ISO 3382-3 [1]. The spatial decay rate describes how much sound attenuates when the distance is doubled and it is determined by calculating the A-weighted sound pressure level at the receiver positions. Distraction distance describes the distance after which the value of speech transmission index falls below 0.5 from person with normal voice. Privacy distance is the distance where the speech transmission index falls below 0,20.

2.2 Building costs

Two different alternatives were studied for open-plan office with modeling. Alternative 1 represents open-plan office which was designed to be acoustically appropriate. In this alternative work stations have been isolated from each other with cabinets and screens. The office ceiling is completely covered with acoustic mineral wool and the floor was covered with textile carpet. In addition, a sound masking system was installed in the space. The A-weighted sound level $L_{A,eq,B}$ of the masking sound was set to 42 dB according to [2,5].

Alternative 2 of the open-plan offices has been designed to fulfill the minimum standard classification D in terms of reverberation time according to standard SFS 5907 [5]. The background noise level $L_{A,eq,B}$ was set to 33 dB. There were no other furniture besides desks in the office. The ceiling was covered with acoustic mineral wool and the floor was covered with plastic carpet.

The material and work costs for furniture, room acoustic material and sound masking system were calculated for alternatives 1 and 2. All costs excluding costs resulting from acoustic decisions were assumed to be the same in both cases. The building costs have been calculated by the cost accounting department of AINS Group. The prices have been calculated without value added tax (VAT 0%).

2.3 Cost effects due to waste of working time

With the use of room acoustic modelling the value of speech transmission index STI was determined around the office (figure 2) when the sound source was at one of four positions at a time. Assuming there was constantly at least one speaker somewhere in the space, we could use the STI value and model presented by Hongisto [4] to calculate the resulted costs.

To determine the loss of working time it is assumed that 90 % of office work time is work that can be charged and price of one hour of work is 60 €/h (VAT 0 %). The sound source is positioned in one of four places at a time and the range of values of speech transmission index has been calculated around the office in all four cases. From the four distributions of the speech transmission index an arithmetic mean has been calculated in both office alternatives 1-2.

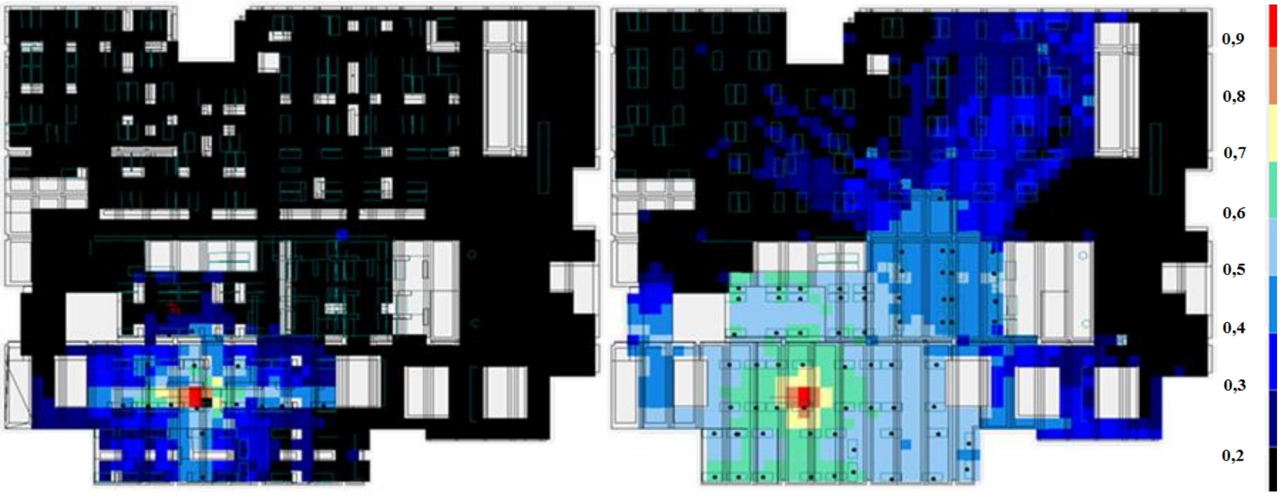

Figure 2: The spread out of speech transmission index (STI) in acoustically designed open-plan office (left) and in open-plan office that meets only the minimum requirements (middle). STI-values between 0 and 1 around the office are presented with different colors (right). Black indicates the lowest values and red the highest values of STI.

The effect of speech transmission index to decreased productivity according to Hongisto [4] is presented in figure 3. The model predicts that performance of complex tasks can be reduced by up to 7 % when speech is highly intelligible [4]. $\leq 0,2$

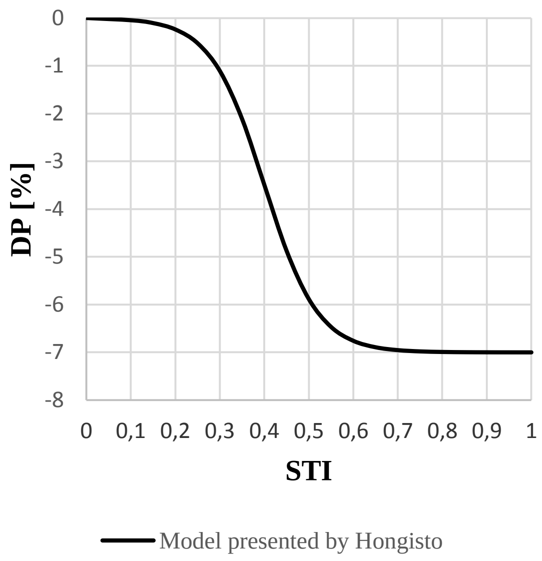

Figure 3: The effect of the speech transmission index (STI) on decreased productivity (DP) presented by Hongisto [4].

2.4 Room acoustic measurements

Measurements were performed according to standard ISO 3382-3 [1] in the actual finished open-plan office in order to verify the modeling results. The measurements included spatial decay rate $D_{2,S}$, distraction distance r_D and privacy distance r_P at three measurement lines that corresponded with the ones used in the modeling. The real office corresponds to the alternative 1. However, there are minor differences in the furniture and their positions between the actual and modeled space. The real open-plan office is presented in figure 4.

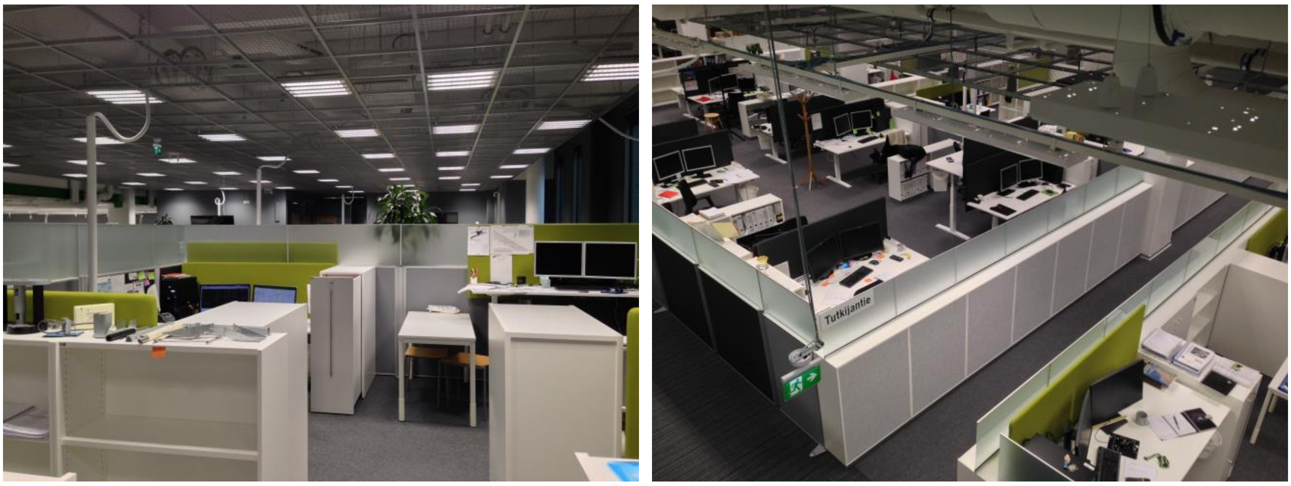

Figure 4: The real open-plan office that corresponds to the modelled alternative 1.

3 Results

The parameters calculated with the room acoustic modelling for alternative 1 and 2 of the office have been presented in table 1. The results for the measurements carried out according to ISO 3382-3 [1] in the actual constructed open-plan office have been presented in table 2.

Table 1: The open-plan office parameters accordant with ISO 3382-3 for the modelled open-plan office alternatives 1 and 2.

Alternative 1 – designed room acoustics			
Measurement path	r_D **[m]**	r_P **[m]**	$D_{2,s}$ **[dB]**
1	4,2	12,8	5,7
2	7,0	13,4	6,9
3	7,7	18,5	5,3
Alternative 2 – meets only the minimum requirements			
Measurement path	r_D **[m]**	r_P **[m]**	$D_{2,s}$ **[dB]**
1	18,2	37,7	2,9
2	20,5	41,0	3,5
3	17,5	41,7	3,4

Table 2: Measured open plan-office parameters in the actual constructed open-plan office.

With masking sound (modeled alternative 1)			
Measurement path	r_D **[m]**	r_P **[m]**	$D_{2,s}$ **[dB]**
1	9,4	18,4	6,3
2	7,8	18,7	6,1
3	10,8	21,1	6,3
Without masking sound			
Measurement path	r_D **[m]**	r_P **[m]**	$D_{2,s}$ **[dB]**
1	22,6	37,1	6,3
2	16,7	31,8	6,1
3	13,3	25,4	6,3

The number of workers within different STI-zones based on the modelling have been presented in tables 3 and 4. Tables also include the cost effects at each STI-zone due to loss of working time based on model of Hongisto [4].

Table 3: The expense due to loss of working time in appropriate open-plan office (alternative 1) during one year.

STI	> 0,8	0,7–0,79	0,6–0,69	0,5–0,59	0,4–0,49	0,3–0,39	0,2–0,29
Employees	1	1	1	4	5	9	9
Expense	1628 €	6477 €	4722 €	17825 €	17116 €	8805 €	2021 €
Total expense							**58595 €**

Table 4: The expense due to loss of working time in an open-plan office that meets only the minimum requirements (alternative 2) during one year.

STI	> 0,8	0,7–0,79	0,6–0,69	0,5–0,59	0,4–0,49	0,3–0,39	0,2–0,29
Employees	1	4	14	20	31	27	19
Expense	1628 €	22669 €	86569 €	109692 €	100253 €	28228 €	4267 €
Total expense							**353306 €**

The expenses for material and installing are 517 711 € in appropriately designed alternative 1 open-plan office. The expenses are 261 774 € accordingly in the alternative 2 open-plan office that meets only the minimum requirements. The expenses have been calculated without value added tax (VAT 0 %).

4 Discussion

Based on the modelling results we can conclude that designing an open plan office to meet only the minimum acoustic requirements exposes a great number of workers to disturbing speech. The material and installing expenses in the open-plan office designed to be acoustically appropriate are double compared to the office that meets only minimum requirements. However, the expenses due to working efficiency are six times greater in the office that meets only minimum requirements compared to the acoustically appropriate office. Based on the results acoustically appropriate office will repay itself within one year. After five years of time the office that meets only the minimum requirements have costed 1,2 million euros more than the acoustically appropriate open-plan office.

The measured spatial decay rate $D_{2,S}$ was greater than based on the modelling. One possible explanation is that the spatial decay due to fixtures, HVAC and other building appliances had been overestimated in the modelling. The distraction distances measured with the masking sound switched on were greater than based on the modelling. This is explained by the fact that the A-weighted background sound level $L_{p,A,B}$ is 42 dB in the modeling but the measured background sound level $L_{p,A,B}$ was on average 38 dB. This indicates that it is possible to achieve the distraction distances of the modelling also in the constructed office by simply increasing the masking sound level.

5 Summary

In this research the room acoustic conditions and their effect on working efficiency were studied as a case study with an open-plan office with 170 work stations. Two different designs were made of the open-plan office with one being acoustically adequate and the other was designed to meet only the minimum acoustical requirements. The building costs were calculated in both cases. The room acoustic properties of the offices were determined with computer modelling and the expenses due to waste of working time were calculated using research literature.

The results indicate that the building costs of acoustically adequate open-plan office are double compared to an office that meets only the minimum requirements. However, the costs due to loss of working time will impact the outcome so that within one year the acoustically adequate open-plan office will be more affordable than the office that meets only the minimum requirements. In five years in the office that meets only the minimum requirements the costs due to loss of working time are eight times greater compared to building costs and the acoustically adequate open plan office is considerably more affordable of the two.

References

[1] SFS-EN ISO 3382-3-2012, Acoustics – Measurement of room acoustic parameters – Part 3: Open plan offices, Suomen Standardisoimisliitto SFS ry, Helsinki, 2012.

[2] V. Hongisto and M. Kylliäinen, Rakennusten akustinen suunnittelu, toimistot, RIL 243-3-2008, Suomen Rakennusinsinöörien Liitto RIL ry, Helsinki, 2008.

[3] J. Kemppainen, Cost effects of acoustical conditions (in Finnish), Master’s thesis, Aalto University, School of Electrical Engineering, Espoo, 2017.

[4] V. Hongisto, A model predicting the effect of speech of varying intelligibility on work performance, *Indoor Air 15*, 2005, 458–468.

[5] SFS 5907-2004, Acoustics classification of spaces in buildings, Finnish Standards Association SFS, Helsinki, 2004.