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Open-plan offices - New Finnish room acoustic regulations

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Summary
New building acoustic regulations took effect in Finland in 2018. The documents involve unambiguous quantitative target values for the room acoustic quality of offices. The target value for the reverberation time is under 0.60 seconds and for Speech Transmission Index under 0.50. The purpose of this paper is to review the present research evidence causing the emergence of the new regulations, the detailed content of the regulations, and questions that should be clarified in the complementary guidelines published during 2018. Other countries are encouraged to take similar actions in their building regulations.

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1. Introduction

Noise and lack of speech privacy are factors causing the largest environmental dissatisfaction among office employees. Problems have increased since 1990's when the share of open-plan offices has continuously increased. The fundamental reason for the problems has been the lack of room acoustic regulations in the previous building code [1]. This has led to the total absence of acoustic design in many office construction projects. An increasing amount of attention has been paid on office acoustics since 2004 but the involvement of an acoustician has been based on voluntary agreements.

New building acoustic regulations took effect in Finland in 2018. The new decree of the Ministry of the Environment [2, 3] involves unambiguous target values for the room acoustic quality of offices. The target value of the reverberation time is under 0.60 seconds and for Speech Transmission Index, *STI*, under 0.50.

The purpose of this paper is to review the present research evidence causing the emergence of the new regulations, the content of the regulations, and questions that should be clarified in the complementary guidelines to be published by the Ministry of the Environment in the near future.

2. Scientific background of new regulations

2.1 Effect of speech on performance

STI is a physical quantity, which is positively associated with subjective speech intelligibility. *STI* values range from 0.0 (no speech intelligibility) to 1.0 (perfect speech intelligibility). The value can be measured between the speaker (a talking employee at point X) and the listener (a disturbed employee at point Y) using standard acoustic measurement apparatus [4]. *STI* values in office context assume that standard speech effort is used (57.4 dB L_{Aeq} at 1 m distance from speaker) so that the measurement results are comparable with each other independent on the measurer.

Hongisto [5] presented a hypothetical model which suggests that unnecessary speech sounds reduce the cognitive performance as a function of *STI* (**Figure 1**).

Thereafter, several psychological experiments have supported the model [6–10]. Perfect consensus will never be reached about the detailed shape of the function within 0.20 and 0.50 because that the effect of disturbing speech on performance depends on task type [5]. There is very strong evidence that reduction of *STI* is associated with reduced cognitive performance of certain short-term memory tasks and that speech might not affect the performance of simple routine tasks.

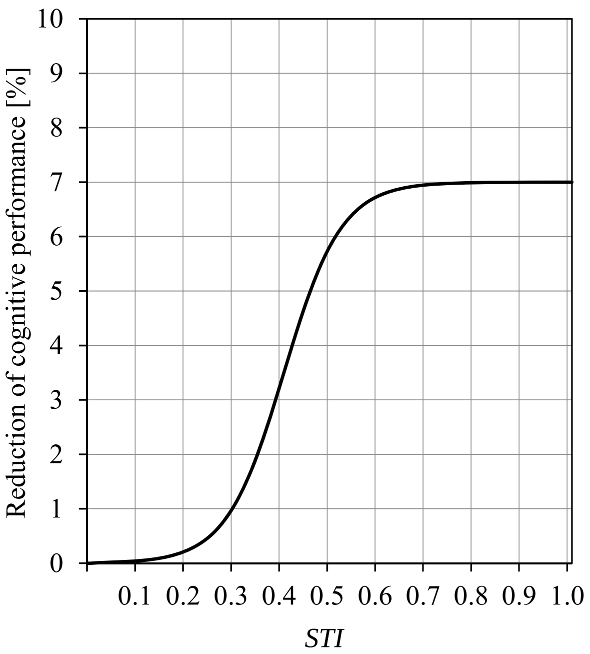


Figure 1. Ref. [5] suggests that cognitive performance reduces with increasing Speech Transmission Index, *STI*, of speech.

2.2 Room acoustic research in laboratory

Room acoustic design principles for open-plan offices were sufficiently documented already in 1957 [11]. Proper room acoustic conditions can be achieved by simultaneous application of sound absorption materials (ceiling, walls and floor), artificial sound masking, and high sound-absorbing and isolating screens between the workstations, if they are appropriate for the work.

These basic principles had to be tested and the findings needed to be translated into such a language that manufacturers, users, and acoustic designers could understand and apply. Therefore, two large laboratory experiments were conducted to test various configurations of absorbers, sound masking, screen height, screen absorption, and room height.

The first large laboratory study focused on two opposite workstations separated by 2.5 meters [12]. It was found that ceiling absorbers and screens have very little effect on *STI* and L_{Aeq} of speech in the opposite workstation if the masking sound level is 33 dB, which was typical in Finnish offices. The importance of sound masking on speech privacy was very strong at such a short propagation distances. However, the smallest *STI* values were achieved when all the acoustic measures, absorption, screens, and masking, were simultaneously used. The authors mentioned that further research is needed to involve longer distances.

The second experiment was conducted in a full-scale open-plan office [13–15] where the measurements could be conducted according to ISO 3382-3 standard [4]. It was found that the role of sound masking was still important but the relative importance of sound absorbers and screens increased with increasing distance from the speaker.

Abovementioned laboratory studies provided a thorough understanding about the impact of room absorption, masking, and screens on *STI* and L_{Aeq} of standard effort speech at different distances from the speaker. The systematic evidence from these two experiments works as a basis for room acoustic design guidelines, education, and further research.

2.3 Room acoustic research in offices

The first room acoustic measurements in offices were also restricted to two opposite workstations [16]. It was soon observed that the restriction to a single short measurement distance does not reveal the full effect of room absorption and screens.

Therefore, a new method was developed in 2007 [17] and published in final form in 2009 [18]. The method involves a measurement of *STI* and L_{Aeq} of normal effort speech at several distances from the speaker. An example of the measurement result of *STI* is shown in **Figure 2**.

The method was the basis of the ISO 3382-3 standard published in 2012 [4]. Many room acoustic prediction software have implemented the standardized method so that acousticians can globally apply the quantities of the standard also during the design phase.

2.4 Perception of acoustic conditions in offices

Office noise could be identified as a major environmental problem in Finnish offices in 2002, when the first questionnaire surveys were conducted. The results were internationally published very late [19–21]. The first cross-sectional surveys suggested that office noise might be even a larger problem in offices than e.g. thermal comfort or indoor air [22]. This was an unexpected result and it took almost a decade to distribute this finding among the building sector. It was a general belief that acoustical conditions were sufficiently solved if the ceiling included some absorption materials, ventilation was silent, and the façade was soundproof against the traffic noise. Especially, sound masking was strongly doubted in 2002 when the first large installation was tested in Finland.

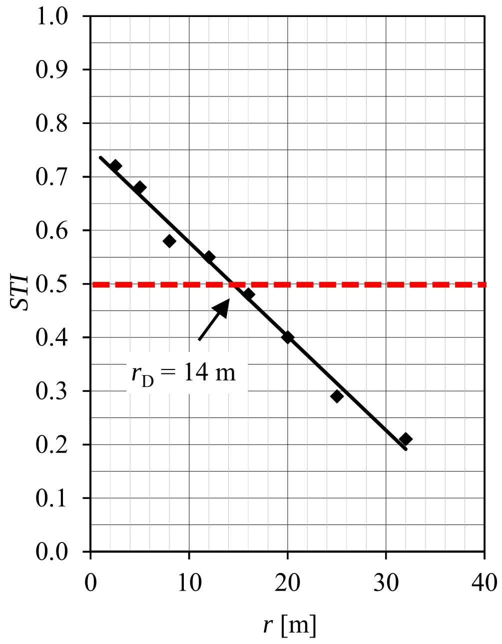


Figure 2. Spatial decay of Speech Transmission Index, *STI*, as a function of the distance from the speaker, *r*, in one office. Distraction distance, r_D [m], is the distance where *STI* falls below 0.50 [4]. The example represents an office with poor speech privacy (class D of **Table I**).

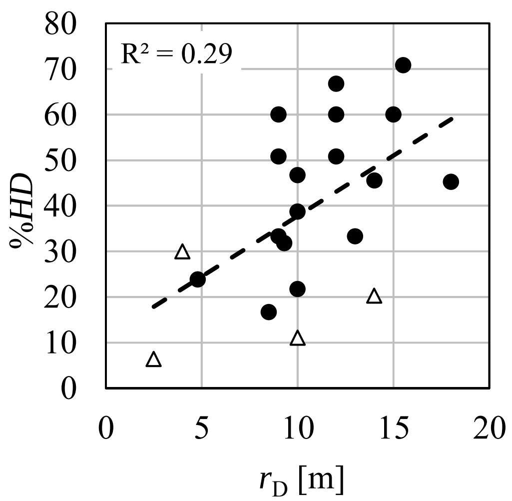


Figure 3. Percentage of employees highly disturbed by noise, %*HD*, as a function of the measured distraction distance of the office, r_D [25]. The study involved 21 offices (circles and triangles) and altogether 883 respondents.

Therefore, a chain of field experiments were started to provide evidence how acoustic improvements can affect environmental satisfaction. Several field experiments were conducted within 2002 and 2014.

Table I. Classification of the three single-number quantities of ISO 3382-3 standard describing the acoustic quality of open-plan offices.

Acoustic class	r_D [m]	D_{2S} [m]	$L_{p,S,4m}$ [dB]
A	<5	>11	<48
B	5–8	9–11	48–51
C	8–11	7–9	51–54
D	11–15	5–7	>54
E	>15	<5	

ISO 3382-3 involves the measurement of *SPL* and *STI* of normal effort speech at different distances from the speaker.
SPL is sound pressure level. *STI* is Speech Transmission Index.
r_D [m] is the distraction distance. It is the distance from the speaker where STI falls below 0.50.
D_{2S} [m] is the spatial decay rate of speech. It is the reduction of A-weighted *SPL* of speech with distance doubling.
$L_{p,S,4m}$ [dB] is the speech level at 4 m. It is the A-weighted *SPL* of speech at 4 m distance from the speaker (interpolated value).

They involved large room acoustic refurbishments and employee questionnaires before and after the refurbishment work [19, 21, 23, 24]. Although these studies could not suggest causality relationships, the results were unambiguously suggesting that investments on room acoustic design could lead to improved acoustic satisfaction.

Very important field evidence on the role of room acoustic quality on noise disturbance in offices was achieved in 2017 [25]. The study involved both room acoustic measurements by ISO 3382-3 and questionnaires in 21 open-plan offices. They found in Ref. [25] that the percentage of employees who were highly disturbed by noise decreased with reducing distraction distance (**Figure 3**). Thus, both laboratory and field studies suggest that reduced *STI* is associated with reduced noise disturbance.

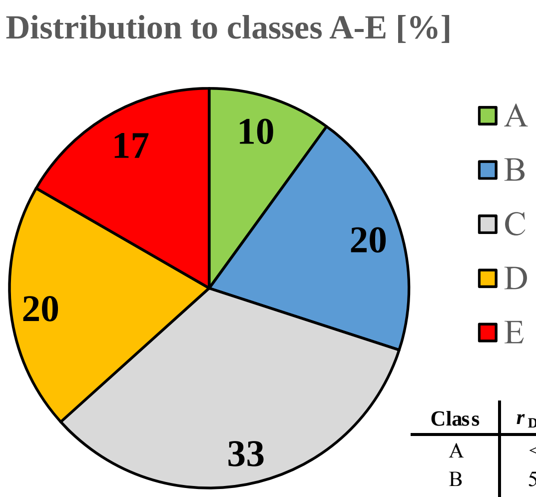
3. Office design guidelines before 2018

As said above, the main reason for noise and speech privacy problems in open-plan offices has been the lack of room acoustic regulations. The previous regulation [1] did not involve any room acoustic target values for offices. Instead, the regulations for ventilation noise were very stringent, 33 dB L_{Aeq}. As a consequence of that, the inherent sound for masking the disturbing speech is absent. This is the main single reason for noise and speech privacy problems. When background noise level is below 33 dB, or even under 30 dB in many cases, normal speech can be perfectly heard even at a distance of 20 meters from the speaker.

Although the relative share of open-plan offices was strongly increasing during 1990's, the authorities responsible for the development of the acoustic building regulations in 1998, nor the acousticians of that time (including the authors), did not yet identify the office noise problem, perhaps because private office rooms were still usual. When the acoustic problems of open-plan offices were identified in 2002, acoustic professionals became aware that mandatory regulations will not be updated before 2015.

The acoustic classification for open-plan offices, involving classes A–D, was suggested already in 2007 to conform the ISO 3382-3 method [17, 18]. The suggestions were applied in two national commercial guidelines used by professionals [26, 27]. The last version of the classification, involving also a class E, is given in **Table I**.

Figure 4 includes the statistical distribution of the distraction distance measured in 29 Finnish offices and one English office [18, 25, 28]. Ten percent of offices are in class A. It shows that class A is not too demanding. Class A offices are rare since very little attention has been paid to room acoustic design. On the other hand, seventeen percent of offices belong to class E. The distribution between classes A and E is almost normal. There has been very little pressure to change the classification of **Table I** since measurement results in offices fall to all five classes. It is a realistic aim to build future open-plan offices to meet either class A or B.



Class	r_D [m]
A	< 5
B	5–8
C	8–11
D	11–15
E	> 15

Figure 4. The acoustic classes of the distraction distances of 30 measured open-plan offices.

4. New regulations for offices 2018

The new regulations are given by the Ministry of the Environment. The regulations consist of a chain of four documents: decree [2], memorandum [3], regulatory instruction, and room acoustic guidebook.

4.1 Decree [2]

The decree is only two-pages-long and it involves two general mandatory requirements for offices:

- "*Soundproofing, noise control and vibration control of office premises must be designed and implemented taking into account the purpose of use of the space, in such a way as to achieve a sufficiently good sound environment corresponding to the operation.*"
- "*The acoustic conditions of the office spaces must be designed and implemented in such a way that, in view of the intended use of the room, sufficient speech intelligibility is achieved.*"

4.2 Memorandum [3]

"*In assessing the fulfillment of the speech intelligibility requirement, the following guideline values could be used in offices:*

- *Reverberation time under 0.60 seconds*

- *Speech Transmission Index under 0.50.*"

If they are not used, the builder must prove by other means that good acoustic environment is achieved. Memorandum suggests that the target values should be achieved in furnished rooms. However, the user cannot be tied to use certain furniture. Therefore, we see that the target values should be achieved in an unfurnished office in the first place. This should be clarified in the room acoustic guidebook.

Memorandum does not clarify the measurement distance of *STI*. **Figure 1** depicted that *STI* depends strongly on the measurement distance. The room acoustic guidebook should clarify the minimum measurement distance from the speaker and integrate the measurement principles of ISO 3382-3 standard to help the acoustic design and verification measurements. Our suggestion is, based on Refs. [13] and [15] that a realistic minimum measurement distance could be 6–7 meters in an empty open-plan office. This corresponds to class B of **Table I**. Furniture could be used to reach class A.

The memorandum involves a limitation to the office types: "*The main office premises, that these requirements concern, would be larger open-plan offices, multipurpose rooms or similar spaces where the nature of the work requires concentration and confidentiality.*" However, most office buildings are built without knowing the job demands for each office space in advance. Even in the opposite situation, the user can later change the job types in the open-plan offices because the organizations and working processes are continuously changed. Therefore, the room acoustic guidebook should clarify that it is recommended to design all open-plan offices using the same target values bulleted above.

The memorandum gives a couple of basic advice on room acoustic design which are feasible based on scientific evidence:

- "*Realizing the requirements for acoustic conditions could be based on sound absorbers, electronic sound reproduction, or a combination of them.*"
- "*In multipurpose offices meant for office work, the aim is to make good speech masking, that is to say, weak speech intelligibility. Speech masking can be improved by artificial systems but they shall be adjustable by their level.*"

Sound masking will be increasingly used. The target values cannot be reached by using ventilation noise as the only masking sound, because it is regulated to be at most 33 dB L_{Aeq}. The state of the art of sound masking research was published in Ref. [30].

4.3 Regulatory instruction

The instruction will clarify the decree and the memorandum. It is published in August 2018 and it involves the quantitative recommendations above.

4.4 Room acoustic guidebook

The guidebook should clarify the room acoustic design of educational and office premises. It is published until December 2018.

5. Holistic noise control in open-plan offices

It is necessary to design the building to meet the new regulations independent of the user's furniture and behavior. The following room acoustic measures shall be considered by the **building owner**:

1. Sound masking system. Global sound masking systems are recommended to produce steady background noise to the office within 160–5000 Hz. Brown noise spectrum is recommended [29]. Water-based sounds should be applied with care [30].
2. Maximization of ceiling absorption. Best available sound absorbers should be installed to cover at least 80% of the ceiling.
3. Maximization of wall absorption. Best available sound absorbers should be installed to cover at least 50% of non-transparent wall areas.
4. The use of textile floor coverings.

The following sound-proofing measures could be considered by the **building owner**:

5. Proper isolation of open-plan offices from aisles, corridors, coffee areas, and fronts of meeting rooms.
6. Provision of anonymous rooms for silent work by an amount of 1 room per 5 employees. Recent evidence shows that a sufficient number of silent workrooms is

associated with speech privacy and environmental satisfaction [31].

The following room acoustic and behavioral means could be considered by the **user**:

7. High screens, preferably 170 cm or more, when the work requires high speech privacy. The screens should be sound-absorbing up to 130 cm height and sound-isolating. Transparent screens can be used above 130 cm [12, 24].
8. Provision of mobile soundproof booths for phone conversations, virtual meetings, and small group working pods in the vicinity of workstations. This is necessary if the number of fixed rooms (point 6) is not sufficient or they are located too far from the workstations. A new method has been developed to measure the acoustic performance of booths [32].
9. Office etiquette. The employees should create a common agreement concerning use of the space and behavior in the space: the silent zones, conversational zones, policy of using silent workrooms, and other means to reduce noise.
10. Headsets. Provision of high-quality headsets during phone calls and internet meetings reduces the noise level in the office and improves the communication.

6. Conclusions

Large scientific evidence has been collected in Finland suggesting that proper room acoustic means could reduce the noise and speech privacy problems in open-plan offices. As a consequence of that, new regulatory target values regarding the room acoustic quality of open-plan offices have taken effect in Finland. Other countries are encouraged to take similar actions in their building regulations.

Acknowledgements

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