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Is the Privacy Index a good indicator for acoustic comfort in an open plan area?

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Abstract [831] Improvement of speech privacy is a major issue in open plan offices and some other open areas. To date, European standards for room acoustics do not propose any convenient and specific measurement units for the rating of speech privacy between workplaces. To some extent, speech intelligibility indices are used for privacy ratings, but they appear not to be appropriate to address the specificity of speech privacy between workstations.
The objective of this paper is to see in what way the established American speech privacy standard could be benchmarked and to some extent complete metrics presently being used in Europe.
The Privacy Index (PI) is derived from Articulation Index (AI) and is a user-friendlier unit, easier to understand for non-specialists. Articulation Index can since some years be measured with special measurement units, but can also be calculated from quick and simple measurements from laptop controlled measuring tools. Behind the Articulation Index is frequency weighted interzone attenuation figures. The weighting factors used are well established and taking into accounts the importance of speech at different frequencies. The connected Articulation Class (AC) gives the interzone attenuation for different products used in open plan areas, like suspended ceilings, office screens, wall panels etc.
For the time being, work is going on to include units like Privacy Index in a standardisation work taking part within ISO/TC 205, dealing with the indoor environment.

1 INTRODUCTION

1.1 Speech Privacy Concepts

The concept of speech privacy is mainly applied for open plan offices. It relates to the degree of speech disturbance between two individuals who are not in conversation with each other. One of them is talking and the other one “happens to hear”:

- From the listener’s point of view, speech is recognized as intrusive since it is not useful to him or her at that very moment. Poor speech privacy will lead to disturbances and bad acoustic comfort.
- From the speaker’s point of view, speech might be of personal character and is “leaking” to surrounding workstations. Poor speech privacy will lead to frustration and bad acoustic comfort.

Since the situation might change to the reverse a short time later (the speaker becomes a listener and vice-versa), poor speech privacy will be perceived as a lack of integrity. Speech privacy has been extensively described by Altman from the socio-psychology point of view [1]. By means of associated concepts of “personal space” and “territoriality”, he argues that physical boundaries are necessary to achieve some desired level of privacy.

The challenge in open plan offices is that such boundaries mainly consist of air. This is supported by Marans' studies [2], showing for instance that the amount of workspace and the degree of visual and acoustical privacy are critical factors to satisfaction in open plan offices.

1.2 Speech Intelligibility

Sometimes speech intelligibility is referred to when it comes to understanding or non-understanding of speech in rooms. The two most common ratings are STI (Speech Transmission Index) and RASTI (RApid Speech Transmission Index). STI/RASTI measurements take into account a set of critical conditions for the acoustics of the room:

- Reverberation time
- Background noise level
- Room geometry
- Location of absorbing/reflecting/diffusing surfaces

STI/RASTI's "positive scaling" of intelligibility is well established; the more understanding of the spoken word, the closer to 1.00. For example, in a normal sized classroom, figures above 0.75-0.80 would be regarded as good. Although recent findings might question the position of the breaking points between different categories on the scale, the professionals consider both STI and RASTI as powerful descriptors of speech intelligibility. Therefore they are widely used in theatres, concert halls and other listening rooms, but nowadays also in classrooms to describe the suitability of a classroom for communication.

The use of STI/RASTI in offices is rare however; the attempts to use it as a descriptor of speech privacy are not satisfactory. The complex nature of speech, including the uneven contribution of the different frequency bands to speech intelligibility is omitted. Since annoyance could occur even though no speech is understood, STI/RASTI does not fully reflect the privacy or comfort situation. Speech intelligibility relates to individuals being in conversation with each other, speech privacy relates to the contrary, where individuals are not in conversation with each other.

On the other hand good speech intelligibility will benefit conversation at short distances and the increased speech comfort consequently leads to a lowered voice. Krakcarz [3] reports a difference of approximately 5 dB, which will reduce the disturbance at surrounding workstations. Therefore measurement of speech privacy should be done separated from reverberation time and speech intelligibility, instead focusing on sound propagation.

1.3 Sound attenuation over distance

In a typical European open plan office layout, the average distance between individuals is 2.5 to 4 metres; at that distance direct sound is dominant. The sound pressure level of speech at that distance is, depending on the overall acoustic conditions, between 50 and 55 dB(A). Here, the capacity of the office design to contribute to the attenuation of sound from the source will play an important role.

Sound attenuation is defined as the decrease of sound pressure level/doubling of distance. In open plan offices it varies a lot, from a few up to 6-7 dB/doubling of distance, for offices fitted with high performance ceiling absorbers, efficient screens and other absorbing vertical surfaces.

As sound energy from speech will decay, the signal-to-noise ratio (S/N) will decrease. Beyond a certain distance, sound will have decayed in such a way that S/N is not sufficient any longer for speech intelligibility. Speech will at that spot be almost "diluted" in the ambient noise of the office.

In order to make S/N more favourable it might be tempting to raise the background noise by some means. Increased background noise is however not recommended as it can have long-term negative effects, such as illness, fatigue, decreased productivity and efficiency. Therefore, European

standards do not recommend attempting to obtain better daily speech privacy by increasing ventilation noise or by use of other sound masking systems.
People are differently sensitive to sound and noise in general, thus no optimal level of background noise will be possible to identify. Privacy and integrity in open plan spaces can only be solved satisfactory by creating separate rooms for confidential discussions, work tasks requiring higher concentration and people being especially sensitive to disturbances.
Speech privacy assessment in offices calls for alternative metrics describing how improved room acoustics affects speech intelligibility. In other words we need a unit to describe how much reduced sound propagation helps to minimize the disturbance from speech from surrounding work stations in an open plan office.

2 ARTICULATION INDEX (AI)

2.1 Definition

Articulation Index (AI) is a signal-to-noise ratio assessment. In an open plan office it reflects the degree to which intruding speech contents, from adjacent work stations, exceeds the ambient sound pressure level at the listener's ear. The sound pressure level of the intruding speech depends on:

- The voice effort of the individual talking
- The orientation of the talker compared to the listener
- The attenuation of the speech over distance
- The attenuation of speech due to the presence of screen and barriers
- The reinforcement of speech due to reflections on surfaces like ceiling, walls, windows, screens, furniture, etc.

Articulation Index is defined in ANSI S3.5 [4] as a standardised method to assess speech intelligibility under a wide range of communication situations, such as noise, filtering, transfer through telephony, reverberation, etc. The Articulation Index ranges from 0.00 to 1.00, with 0.00 representing zero intelligibility and 1.00 complete intelligibility. It is calculated by:

$$AI = \sum W_i \times R_i \qquad (1)$$

Where:
AI = Articulation Index
W_i = Weighting Factor for respective one-third octave band, see Table 1.
R_i = Signal-to-Noise ratio for respective one-third octave band (200-5000 Hz)

Articulation Index concerns the transmission of critical speech frequencies from one point to another in a room. Weighting factors will then emphasize the ability of the fittings to attenuate the propagation of speech elements contributing most to intelligibility. Critical elements for intelligibility are typically located in a frequency range of 500 to 5000 Hz, irrespectively of gender.

Hz	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
W_i	.0004	.001	.001	.0014	.0014	.002	.002	.0024	.003	.0037	.0038	.0034	.0034	.0024	.002

Table 1: *Weighting factors according to ANSI S3.5*

Signal-to-Noise ratio calculations and/or measurements should consider four different speech situations: "normal voice", "raised voice", "loud voice" and "shout". That means ANSI S3.5 does not address "lowered voice", which seems to be the situation in open plan spaces, where people speak at a lower level. A typically 3 to 10 dB lower voice level must be taken into account in the calculation.

There has been a revision of ANSI S3.5 some years ago, where the term AI was changed to SII, Speech Intelligibility Index. The review clarifies the contribution of masking effects, speech spectrum levels and the relative importance of various frequencies to speech intelligibility. This revision has no direct connection to privacy in open plan spaces and it seems that there is no adoption of SII in this field so far. Several ASTM standards in the field of speech privacy, being revised years later, have neglected the change.

2.2 Interpretation

According to Hedge [5] Articulation Index correlates well with the percentage of people satisfied with speech privacy. Some breaking points have been established through research and experiments. For instance Horrall [6] reports "Many people are not satisfied if AI is more than about 0.20".

ASTM E 1374 [7] (Standard guide for open office acoustics) gives some general advice concerning AI and other details. It says for example that speech privacy is considered being confidential, when speech can be detected, but not understood. This corresponds to an AI of less than or equal to 0.05. It does also define speech privacy as being normal or non-intrusive, when an effort is required to understand speech. In these conditions speech is not a source of distraction. With AI values greater than 0.20 speech becomes more readily understood and at values greater than 0.40 there is basically no privacy. Some professionals describe AI values greater than 0.30 as unacceptable privacy.

2.3 Privacy Index (PI)

Articulation Index was originally developed to rate communication rather than privacy. However AI was adopted by ASTM E 1130 [8], dealing with objective measurement of speech privacy. Unfortunately there have been some difficulties to understand and explain Articulation Index, due to its inverse scaling. In the 2002 version of the standard an appendix was added giving an alternative single number rating for speech privacy, called Privacy Index (PI). It is expressed in percentage and can easily be calculated from AI by the following expression:

$$PI = (1 - AI) \times 100\% \qquad (2)$$

Where:
PI = Privacy Index
AI = Articulation Index

Consequently, confidential speech privacy is achieved at PI values of 95% or more. Normal speech privacy corresponds to PI values between 80 and 95%.

Privacy Index is assumed to be easier for users to understand and seems to have gained wide spread among acousticians in North America. Horrall [6] says "a Privacy Index of 90% is really understood as a good privacy by most people, while an Articulation Index of 0.10 is not, despite the fact that they are exactly comparable".

3 ARTICULATION CLASS (AC)

3.1 Definition

Privacy in open plan offices is system related, which means that privacy is achieved through a combination of performance of fittings integrated in the office; ceiling, screens, furniture, etc. In that respect Andersson [9] and other authors have pointed out that a screen will only be effective in combination with good absorbing ceilings.

Acoustical performance rating of building elements or fittings integrated in the design of an office should take into consideration their capacity to absorb speech sound energy efficiently in the critical frequency bands pointed out for Articulation Index calculation.

This performance is in the ASTM terminology called "interzone attenuation", which is a sound abatement measurement for open spaces divided into zones by mean of barriers (screens). ASTM covers performance measurements of interzone attenuation for three different components:

- Ceiling systems according to ASTM E 1111 [10]
- Barriers according to ASTM E 1375 [11]
- Wall finishes and Furniture panels according to ASTM E 1376 [12]

3.2 Interzone attenuation of ceiling systems

The measurement of interzone attenuation demonstrates the sound reflective characteristics of ceiling systems when used in conjunction with a well-defined partial-height barrier. This arrangement is commonly used in offices in order to achieve some speech privacy between working places. The interzone attenuation is calculated as the difference in sound pressure level between the reference point for the loud-speaker source and the receiver microphone for each one-third octave band in the frequency range 200-5000 Hz and at 8 different distances.

3.3 Calculation of Articulation Class (AC)

Articulation Class is the result of a calculation according to ASTM E 1110 [13] from the interzone attenuation provided by a single component. AC is used as a tool to classify and compare for example ceiling systems, the higher the AC value the better the speech privacy in an open plan space.

Articulation Class shows the performance of individual components and fittings, which affect speech privacy. AC is a weighted single value using scaled ANSI S3.5 weighting factors defined for Articulation Index. For each distance the weighted interzone attenuations for all involved frequencies are added together and rounded off to the nearest multiple of 10, giving the AC value for a certain distance. The lowest AC figure for the different distances shall be presented and expressed as Minimum AC value.

3.4 Evaluation of Articulation Class (AC)

Different ceiling systems have been tested for the minimum AC value, see Table 2.

Type of product	AC value
Micro perforated painted surface on 40 mm glass wool core	200
Micro perforated painted surface on 20 mm glass wool core	180
Fissured patterned painted surface on 16 mm wet-felt core	150
Micro perforated 13 mm plaster board with acoustic tissue back	150

Table 2: *Minimum AC values*

A high Articulation Class gives some speech privacy; a lower AC value means lower privacy. American acoustic consultants usually refer to suspended ceiling systems with minimum AC 180 in order to achieve some kind of acceptable speech privacy for normal working tasks. Confidential conversation and work tasks demanding concentration need even better privacy.

The challenge is to link the product based Articulation Class with the system based Articulation Index to enable predictions of a certain workplace before installation. Weighting factors used both for AC and AI are in principle the same from ANSI S3.5, only that a scaling factor is applied for the AC calculation. Since AC and AI evaluate the influence of speech in the same way, inclusion of products with high Articulation Class in the design of an open plan space should lead to a decrease in Articulation Index, being equal to an increase in Privacy Index.

4 FIELD OF APPLICATION

4.1 General

An application of a speech privacy metric, like AI or PI, requires that measurement is standardized to allow comparison, independently of conditions and operator. It should be measurable and controllable in regards of targeted value and it should show enough variance to motivate adjustments, improvements and development.
ASTM E 1130 says that speech privacy is a measure of the privacy resulting from a particularly configuration of open office components. It applies therefore to fully fitted and furnished environments. It is based on the Articulation Index or the Privacy Index method and reflects the speech privacy conditions between two positions in a room.

4.2 Measurement of Articulation Index/Privacy Index

Measurement devices for Articulation Index/Privacy Index exist and have been used, not only in North America, for several years. Delage & Delage [14] used it for instance as a way to quantify the outcome of a number of acoustical improvements at an insurance company office.
Over the years, the instrumentation for such measurements has been aided by development within the field of sound recording as well as the development of laptops. Horrall [6] writes that a portable computer with integrated soundboard and a suitable amplified loudspeaker and test microphone are all that are needed to perform in-situ measurements of Articulation Index or other accepted indices of speech privacy. Along with modest training, such instrumentation allows technicians to survey a large number of working places economically. There are cost efficient tools meeting the requirements for testing in most common environments where oral privacy is likely to be required.

4.3 Measurement of Articulation Class

Experiments conducted under laboratory conditions indicate that AC is a more sensitive descriptor of sound attenuation than A-weighted sound pressure level (L_{pA} dB). In a paper Andersson [9] refers to a test series conducted on comparative AC measurements in the presence of added absorbing elements below an acoustic ceiling, so called free hanging units. The purpose of the tests was to investigate means to further improve speech privacy in premises, where already a high AC level is achieved. The measurements were carried out according to applicable parts of ASTM E 1111.
Results indicate a higher sensitivity to Articulation Class in the most upgraded configuration, than that of sound attenuation values expressed as L_{pA}. The AC value increases significantly along with the five configurations tested and reaches 210, which is very high. The improvement measured as L_{pA}, is for the same configuration only a few dB. This experiment illustrates lack of sensitivity to the most important frequencies for speech recognition using L_{pA} as a descriptor. Thereby the tests confirm the need of specific metrics to properly describe measures taken to attain sufficient speech privacy in open plan solutions. Thanks to the reactivity of Articulation Class a similar reactivity will

arise in Articulation Index/Privacy Index, meaning that minor changes and adjustments in an office design will have a significant impact.

5 SUMMARY

Privacy Index (PI) might be a good instrument for the definition of the acoustic quality of open plan office spaces where speech privacy is important. ASTM provides a complete set of standards for the application of Privacy Index to speech privacy in open plan solutions, see Figure 1.

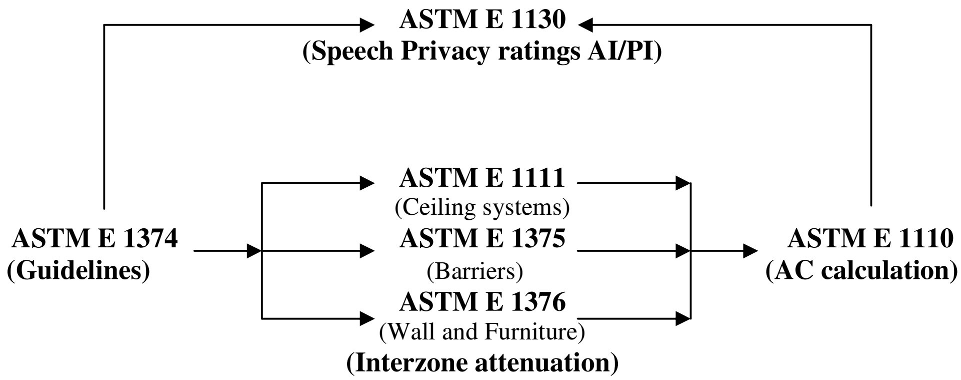

Figure 1: *ASTM flow chart*

Finally, thanks to the same speech weighting, descriptors of the acoustic environment and comfort in an office (Privacy Index) can be related to performance of office fittings (Articulation Class). This creates a firm base for the implementation of Privacy Index and Articulation Class in European standardisation. The research behind the standardisation of Articulation Index allows for a use of the method with other languages than English. This way, standards including speech privacy metrics will provide support to all building phases of open plan offices:

- Expression of requirements
- Calculation and prediction
- Specifications of various fittings
- Verification and control

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