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Sound Decisions: Moving forward with Acoustics

Improving Speech Privacy and Acoustic Comfort In Offices

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ABSTRACT

Sound masking systems (SMS) were introduced in the 1970s to improve speech privacy in open plan offices by establishing a constant, controlled minimum background sound level. Today, most SMS contain timer programs. These attempt to balance the need to raise sound levels during busy periods for greater speech privacy, whist lowering the sound level during calm periods for acoustic comfort. However, in modern offices, occupancy levels vary more unpredictably during the day, and from one day to another, reducing timer system efficiency.

To address this, an Adaptive Volume Control (AVC) algorithm has been developed, which is based on real-time statistical analysis of the sound pressure level and uses the difference between the L10% and L99% to adjust the sound level. Using measurements of 5-day noise levels in three different types of open-plan offices, this paper quantifies the variations in speech privacy and acoustic comfort efficiency resulting from different minimum background sound levels controlled by SMS that are (a) fixed-level, (b) timer-controlled, and (c) AVC-controlled. Depending on office occupancy, results demonstrate that occupant acoustical comfort was improved by up to 50% and speech privacy was improved by up to 15% compared to the timer-controlled levels.

1 INTRODUCTION

The principle of sound masking is the emission of a soft, neutral and non-disturbing sound to mask and blend out noise distractions, mainly voices travelling throughout the office, in order to improve speech privacy and acoustic comfort in offices.

Since their introduction, various features have been added to improve the performance of sound masking systems (SMS). Amongst other things, the need to increase and decrease the masking sound level depending on the activity within the workspace was recognized, and programmable timer functions were introduced (Chanaud, 2008). Today, performance specifications for a typical sound masking system generally request a timer function, so as to allow for the setting of the masking volume according to a schedule for each independent zone.

Timer functions may be set-up to increase the volume in the morning and decrease it in the evenings and nighttime, or indeed based on a schedule devised by the programmer to reflect low and high activity periods. The effectiveness of the timer function assumes that the activity levels are relatively constant during the higher-activity periods (i.e. the typical workday). This assumption is questionable however, especially in modern offices with flexible conditions, activity-based working, and non-assigned work and interaction spaces becoming common.

2 VARIABILITY OF DAYTIME NOISE LEVELS IN OPEN PLAN

Bradley showed, using measurements spread over 700 open offices, that the average daytime sound level in an open-plan office varies within an almost normal distribution between 38 and 55 dBA, with 90% of values contained within this range (Bradley, 2004). The question here is to what extend these sound levels are constant or vary throughout the daytime working hours. To answer this question, the noise levels measured in various open spaces were analyzed. The noise levels were measured just below the suspended ceiling to avoid the effect of a single local sound source dominating (such as a voice coming mainly from a given workstation) and to attempt obtain the cumulative level of voices coming from multiple workstations.

Figure 1 presents typical results obtained for a) a small open space (10 workstations), b) a medium open space (20 workstations), and c) and d) two different locations within a large open space. The graphs on the left present the $L_{Aeq,1h}$ over a week, and the graphs on the right present the statistical distribution of the levels over the working hours period (8:30AM - 5:00PM, Monday to Friday).

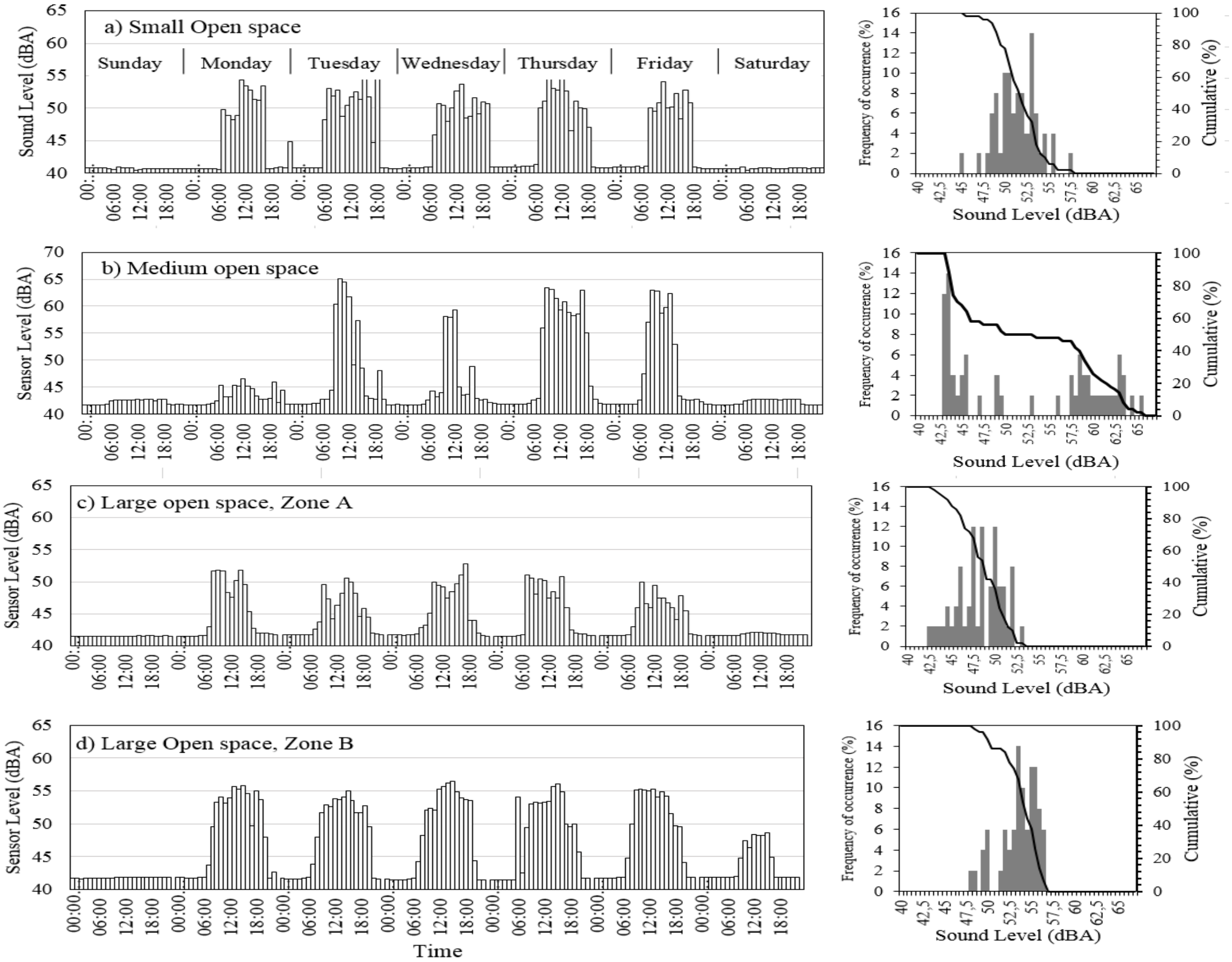

Figure 1: $L_{Aeq,1h}$ over a week, and their statistical distribution over the working hours period (8:30AM - 5:00PM, Monday to Friday) for a) a small open space, b) a medium open space, and c) and d) two different locations within a large open space.

Obviously, the $L_{Aeq,1h}$ noise levels are higher during working hours, typically between 8:30AM and 5:00PM, but there are significant variations from hour to hour, from one day to another, and from one location to another. The statistical distribution of the $L_{Aeq,1h}$ is approximately normal, with a standard deviation of about 10 dB in all cases. It can also be observed that in zone B of the large open office (a call centre), the noise levels due to activity were significant on Saturday.

If $L_{Aeq,15m}$ levels are considered instead of $L_{Aeq,1h}$, then more variations throughout the day can be observed (see Figure 2). This is simply the consequence of noise events within workspaces (most of the time due to people talking) starting and stopping intermittently. If $L_{Aeq,5m}$ levels are considered, the variation becomes even more important.

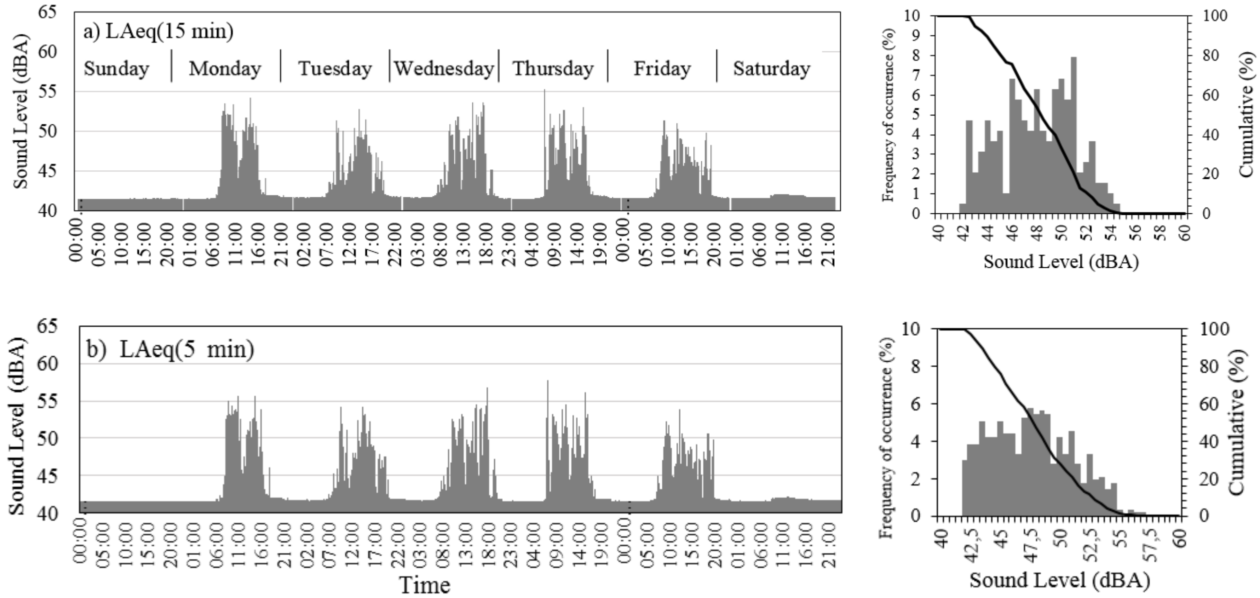

Figure 2: a) $L_{Aeq,15m}$ and b) $L_{Aeq,5m}$ in zone A of the large open office of Figure 1c, and the statistical distribution during the working hours (8:30AM - 5:00PM, Monday to Friday).

3 AUTOMATIC VOLUME CONTROL

3.1 Timer Function Volume Control

A timer function volume control attempts to anticipate activity levels based on the programmers knowledge of the workspace. For example, increasing the sound volume in the morning, lowering it during lunchtime and raising it again for the afternoon, and finally lowering it again in the evening for the nighttime period. While being very simple to implement, this timer function lacks the ability to adapt to the varying activity levels of the modern office environment. The predefined masking sound level can be too high and thus disturbing in low-activity environments, and too low and thus ineffective in high-activity environments. Furthermore, timer systems need to be reconfigured if a change in work hours occurs.

3.2 Conventional Automatic Volume Control

A conventional automatic volume control, like those used for the television sets in waiting rooms, are analog devices that can increase or decrease the volume according to the instantaneous ambient sound pressure level (SPL). However, these devices rapidly respond to short noise events, and can increase (or decrease) the masking sound level sharply and significantly, 3 dB or more in a couple of seconds. Such variations of the masking sound levels are clearly perceived by the users and lead to discomfort. These volume controllers are thus not well adapted for sound masking systems.

3.3 Automatic Volume Control Based on Statistical Analysis

In an effort to correct the problems related to conventional automatic volume controls, an automatic volume control algorithm based on the statistical analysis of the SPL was developed (L' Espérance *et al*, 2007).

Figure 3a shows the SPL fast measured in an open-space for a typical daytime morning. When there are only a few disruptive noises in an office (few conversations and intermittent noises), the noise levels are quite stable, and the statistical distribution of sound levels is small (Figure 3b). On the contrary, when the voices and/or noises due to human activities increase, important variations in the ambient sound environment occur, and the statistical distribution of the sound levels is significantly larger (Figure 3c).

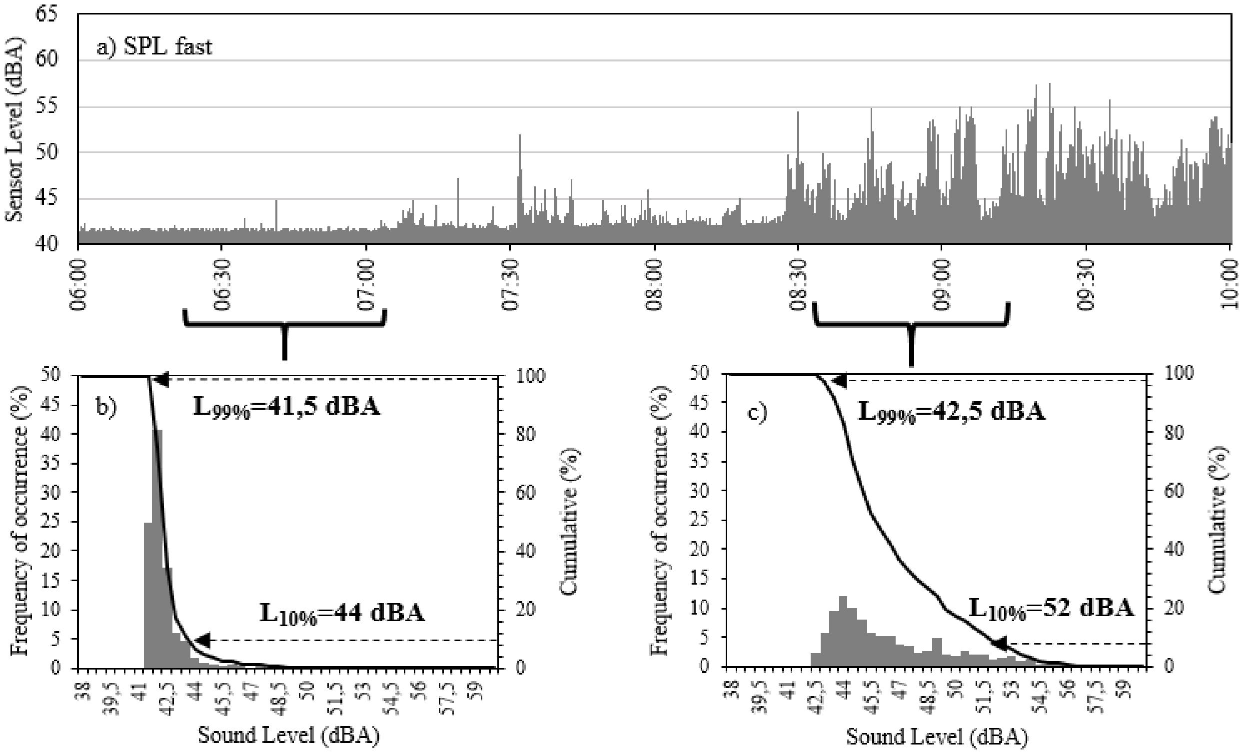

Figure 3: SPL fast for a typical morning, and the statistical distribution of the noise levels a) before and b) after an increase in voices and/or noises due to human activities.

It can be seen that a few speech or noise events result in a small difference between the L10% and L99%, whilst many speech or noise events will lead to a large difference between L10% and L99%. The difference between the percentile levels L10% and L99%, denoted *ΔL10-99*, thus appears to be an efficient parameter to quantify the level of potentially disturbing noise in any given office or workplace.

3.3.1 Adaptive Volume Control (AVC) of Masking Sound Level

When disturbing noise events increase, the *ΔL10-99* increases and the sound masking level should be increased to protect speech privacy and reduce distraction. When the *ΔL10-99* decreases, the sound masking level should be reduced to maintain acoustic comfort. To obtain the desired behavior, the following function can be used:

$$AVC\ (dB)\ =\ W\ *(\Delta L10-99 - TgL10-99) \qquad (1)$$

TgL10-99 is the target difference between L10% and the L99%. When *ΔL10-99 – TgL10-99* is positive, the system increases the sound masking accordingly. If the difference is negative, the system decreases the masking sound level. *W* is an adjustable factor that allows weighting of the resulting difference, making the system either more or less sensitive.

As an example, if *TgL10-99* is set to 10 dB and the system measures a *ΔL10-99* of 15 dB (an acoustical environment with significant noise events) and the weighting factor W set to 0.5, the algorithm will set the increase of the masking level to an AVC Gain of +2.5 dB.

3.3.2 Statistical Analysis Time Period

The length of the time period considered for the statistical analysis, the TSA, will determine the sensitivity of the system to react to sporadic noise events or to more general trends in changes of the acoustic environment. A short TSA will make the system react rapidly to sporadic noise events, whereas a longer TSA will allow the system to react to longer trends of the acoustic environment. Evaluations performed for many sound masking installations have shown that a TSA of 15 seconds provides a rate of change that is well adapted for open and closed office environments.

3.3.3 Maximum Change Rate

To ensure a smooth and undetectable variation of the masking sound volume, the change rate in dB/s can be set. For instance, if the controller requests an AVC gain of +3 dB and if the maximum Up-Rate is set to 0.05dB/s, the sound masking will take about 1 minute to reach 3 dB. In a working environment, such a change is imperceptible to the vast majority of people.

3.3.4 Maximum and Minimum Masking Sound Level

To avoid any discomfort, the masking sound level must be limited to a maximum and minimum level. The maximum masking sound level depends on the desired masking effect and degree of comfort. These values may be specified by an acoustician. Typically, the maximum masking sound level should be set to 45 dBA for an optimal sound masking effect, and up to a maximum of 48 dBA (Bradley, 2003). Above this 48 dBA limit the sound masking itself may cause discomfort (Bradley, 2003).

Employing a minimum masking sound level preserves a minimum degree of speech privacy and a comfortable acoustical environment. Based on Soft dB's experience on hundreds of installations with AVC control, a sound masking level of 42 dBA in a calm open-plan office creates a smooth acoustical environment that is appreciated by the occupants. Whilst this would be recommended, this minimum masking level can be set to meet any level set by the acoustician's technical specifications.

3.3.5 Effect of Different Parameters on the Adaptive Volume Control Algorithm

To present the effect of the *TgL10-99* and *W* parameters of the AVC algorithm, the results obtained in medium size open-plan offices (Figure 1b) will be used since there are different levels of activities from one day to another (from calm to relatively noisy).

Figure 4a presents the $L_{Aeq,15s}$. The average noise level for the whole working day (8:30AM - 5:00PM, Monday to Friday) is provided on the top of the Figure. This daytime equivalent level provides an indication of the degree of noisy activities during the day. Figure 4b presents the adaptive volume adjustment obtained with the standard parameters of the AVC algorithm: *TgL10-99* = 7.5 dB, *W* = 0.5, step-up & down of 0.025 dB/s. The minimum masking sound level is 42 dBA and the maximum is 45 dBA (hence 3 dB of adaptive volume control). Figure 4c uses a smaller value of *TgL10-99* = 3 dB. Figure 4d shows the effect of a large weighting factor (W= 4).

If *TgL10-99* is reduced to 3 dB instead of 7.5 dB, the control algorithm will increase the sound masking even if there are only a few noise variations (Figure 4c). If the weighting factor *W* is set to 4 instead of 0.5, the volume control becomes more sensitive (Figure 4d). In this situation, it reacts essentially like a timer control with an on/off behavior but with greater intelligence since the masking sound level is set at its minimum when there are no disturbing noises (such as Monday morning in the previous example). The adaptive volume control algorithm thus provides a very high degree of flexibility and control.

An extensive evaluation of more than 500 sound masking office installations led to the refinement the parameters, thus optimizing the acoustical comfort and degree of speech privacy provided. The optimized parameters are: *TgL10-99* = 7.5 dB, *W* = 0.5, and maximum volume change rate of 0.025 dB/s.

In practice, the parameters of the AVC are set to these default values and generally do not require further adjustment. The efficiency of the sound masking systems on the acoustical comfort and speech privacy can however be evaluated after a representative period using the data obtained on site from the integrated sound level sensors.

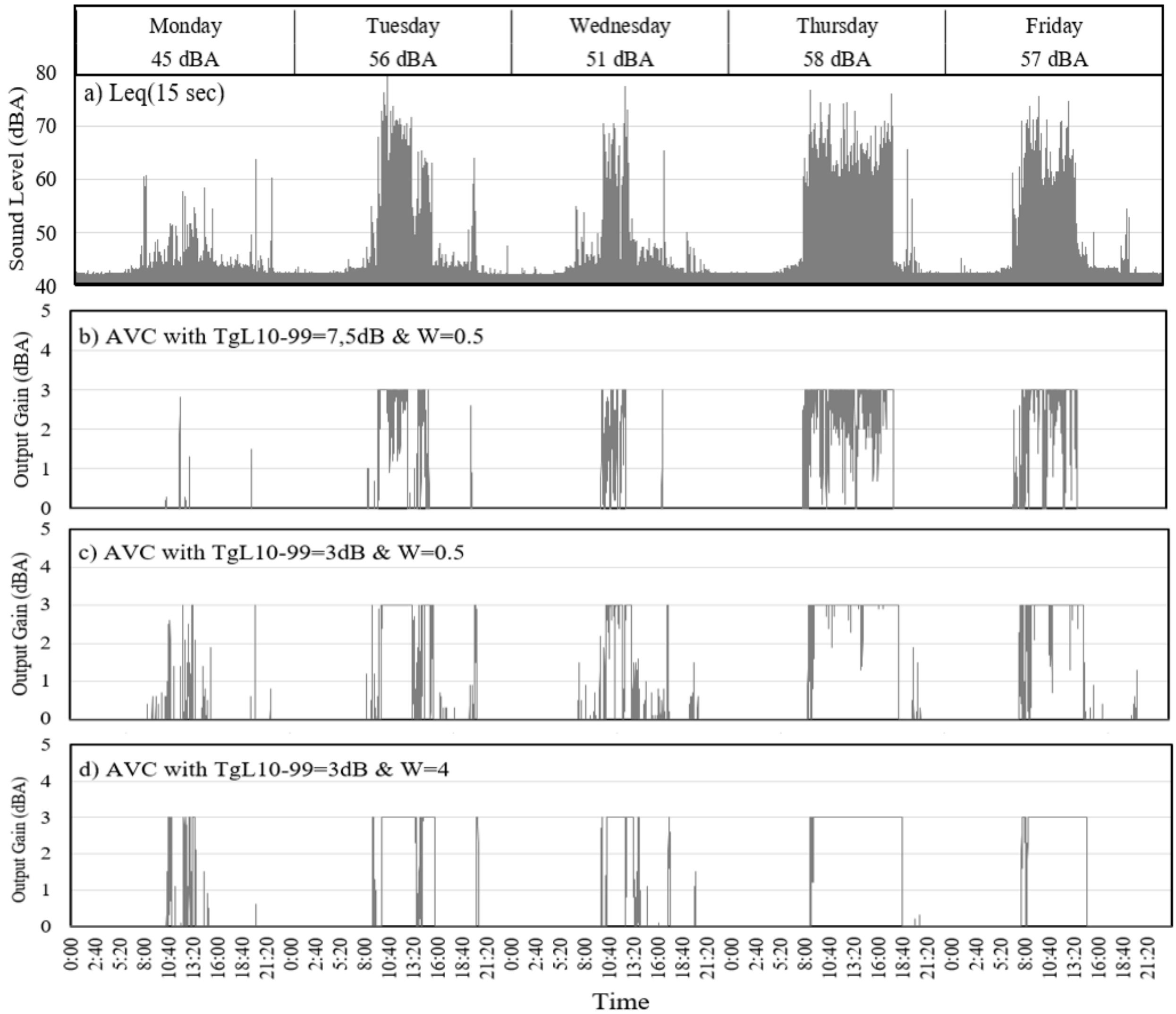

Figure 4: a) $L_{Aeq,15s}$ and average noise levels for the whole working day (8:30AM - 5:00PM, Monday to Friday) b) Volume Adjustment obtained with standard parameters: *TgL10-99* = 7.5 dB, *W* = 0.5; c): same as previous, but *TgL10-99* = 3 dB; and d): *TgL10-99* = 3 and W= 4.

4 EVALUATION OF COMFORT AND SPEECH PRIVACY

4.1 Improvement of Acoustical Comfort

As describe by Bradley, “The degree of acoustic comfort in an open-plan office is related to the combined effects of unwanted ambient noise and a desired level of speech privacy” (Bradley, 2003). It is generally accepted that a masking sound level of 45 dBA is considered optimum and 48 dBA the upper limit over which sound masking itself may cause discomfort (Bradley, 2003).

That being said, if the overall noise level (L_{Aeq}) in the office is significantly higher than the sound masking level (Lmk), then the sound masking itself will not be noticeable by the occupants and will not generate discomfort even if it is higher than 45 dBA. However, if the acoustical environment is calmer, with only a few disturbing noise events, the L_{Aeq} will be more or less equal to the Lmk and the masking sound may be more noticeable and could generate discomfort even if it is set to the optimum level of 45 dBA.

As such, in an effort to give more nuances to the general guideline, this difference between the ambient sound level L_{Aeq} and the masking sound level Lmk (thus ΔL_{Aeq}-Lmk) is an appropriate metric to evaluate the potential discomfort related to the sound masking.

The minimum value for ΔL_{Aeq}-Lmk where discomfort may begin to appear is subjective. Considering that 0 dB means that the masking sound is the most significant sound of the environment, and that a difference of 10 dB makes the masking sound almost undistinguishable compared to the overall ambient noise, a value of 5 dB for ΔL_{Aeq}-Lmk could be taken as a reasonable value to evaluate the point at which discomfort due to the dominancy of the masking sound may begin to occur. In addition, it can be agreed that a low level of masking sound will not create any significant discomfort (about 42 dBA according to Soft dB experience). A masking sound level lower than 42 dBA (Lmk<42 dBA) should therefore be considered as comfortable even if the L_{Aeq} is not 5 dB above Lmk.

Table 1 below presents the percentage of the time for which the comfort criteria was respected (L_{Aeq}-Lmk > 5dB || Lmk < 42dBA) for the five working days of Fig 4. Each column presents the results for the different days as a function of increasing noise activity. The results are provided for a constant working-day masking sound level of 45 dBA provided by a timer function, and for two Adaptive Volume Control with different maximum limits: 42-45 dBA, and 42-48 dBA.

Table 1: Evaluation of Acoustic Comfort: Percentage of time respecting the comfort criteria

Leq (8h30 - 17h)	**Calm** **45 dBA** (Monday)	**51 dBA** (Wednesday)	**55 dBA** (Tuesday)	**57 dBA** (Friday)	**Active** **59 dBA** (Thursday)
Timer constant 45 dBA	2%	31%	56%	45%	92%
AVC with 42 to 45 dBA limits	98%	98%	94%	96%	97%
Improvement on comfort (AVC relative to Timer)	96%	67%	39%	51%	5%
AVC with 42 to 48 dBA limits	98%	97%	94%	96%	96%
Improvement on comfort (AVC relative to Timer)	96%	67%	39%	51%	4%

Note that if a value of 3 or 10 dB is considered for the L_{Aeq}-Lmk parameter instead of 5 dB, the % time where the comfort criteria is respected will change, but the improvement in comfort due to the AVC relative to the timer function will be similar.

The results of Table 1 show that, in a calm environment (Daytime L_{Aeq} of 45 dBA), the comfort criteria are respected only 2% of the time when using a fixed sound masking level of 45 dBA provided by a timer function. By contrast, with the AVC set to 42-45 dBA, the comfort criteria are respected almost 98% of the time, which is an improvement of 96% compared to the constant masking volume. In a moderately active day (Daytime L_{Aeq} of 51, 55 and 57 dBA), the improvements in comfort are respectively 67%, 39% and 51%. For a very active day (Daytime L_{Aeq} of 59 dBA), the improvement is less significant (5%), which is to be expected as the masking level plateaus at 45 dBA for almost the entire day.

4.2 Improvement in Speech Privacy

Standardized methods exist to evaluate the speech privacy between two closes offices or workstations (ASTM E1130, 2016; ASTM E2638, 2010, Bradley and Gover, 2010).

However, these methods cannot be applied by using the overall noise level measured just under the suspended ceiling, which is the only data available in this study. To evaluate the improvement (or reduction) in speech privacy provided by the AVC compared to a constant sound masking level, a proposed metric can be to compare how often the L10% significantly exceeds the masking level Lmk of both systems. A significant exceedance in this instance was defined as +15 dB. Thus for the purpose of this analysis, the criterion *L10%<Lmk+15 dB* was considered. Essentially, the more often the criterion is met, the better the speech privacy should be.

Table 2 presents the percentage of the time for which the *L10% <Lmk+15dB* for the five working days of Figure 4. Each column presents the results for the different days as a function of increasing noise activity. The results are provided for a constant masking sound level of 45 dBA provided by a timer function and for two Adaptive Volume Control maximum limits: 42-45 dBA and 42-48 dBA.

Table 2: Evaluation of Speech Privacy: Percentage of time respecting the privacy criterion *L10% <Lmk+15dB*

Leq (daytime:8h30-17h)	**Calm** **45 dBA** (Monday)	**51 dBA** (Wednesday)	**55 dBA** (Tuesday)	**57 dBA** (Friday)	**Active** **59 dBA** (Thursday)
Constant Lmk: 45 dBA	100%	92%	69%	73%	51%
AVC with 42-45 dBA limits	100%	92%	69%	72%	51%
Improvement on privacy (AVC relative to Timer)	0%	0%	0%	-1%	0%
AVC with 42-48 dBA limits	100%	93%	78%	80%	66%
Improvement on privacy (AVC relative to Timer)	0%	1%	10%	7%	15%

Note that if the exceeding values of 12 or 18 dB are considered instead of 15 dB, for example, the percentage of time respecting the comfort criteria will change, but the improvement in speech privacy from the timer function to the AVC will be similar.

When comparing the constant masking sound level of 45 dBA and the Adaptive Volume Control set to 42-45 dBA, the percentage of time that the privacy criterion is respected appears to be identical. In fact, the reduction of speech privacy appears to be less than 1% on calm, moderate, or active days. As such, it can be concluded that an AVC provides the same degree of speech privacy as a timer function that provides a constant masking sound level with the same higher limit of 45 dBA.

If the higher limit of the AVC is increased to 48 dBA instead of 45 dBA, the percentage time the privacy criterion is respected goes from 72% to 80% (for a moderately active day) and from 51% to 66% (for the high activity day). Thus, the improvement in speech privacy due to the use of the adaptive system can be seen to be a relative increase of 8% and 15% for days of moderate and high activity respectively. As shown in Table 1, this improvement in speech privacy can be obtained at the same time as a significant improvement in the acoustical comfort.

5 CONCLUSION

To improve the acoustical comfort of a sound masking installation in offices, the need to increase and decrease the masking sound level depending on the activity is well recognized. Since the end of the 1970's: programmable timer functions were developed to answer this need as much as possible. However, measurements performed in modern open-plan offices show that noise levels vary significantly during the day, and from one day to another.

To improve the effectiveness and comfort of sound masking installations, an Adaptive Volume Control algorithm has been developed. This AVC algorithm is based on real-time statistical analysis of the SPL and uses the difference between the L10% and L99% to set the volume adjustment. Parameters can be set to make the volume adjustment more or less sensitive to noise activities in the room to make the volume changes more or less responsive.

A number of simulations and analyses based on the noise levels measured in real offices with sound masking systems installed were performed to determine the typical values of these parameters to optimize the acoustical comfort and speech privacy for most cases. An analysis of the difference between the ambient L_{Aeq} and the masking sound levels on various days with different levels of activity has been undertaken.

When the lower and upper limits of the AVC masking system are set to 42 and 45 dBA respectively, the speech privacy obtained is almost identical to that obtained from a constant masking sound level of 45 dBA that would is provided by a timer function. However, the acoustical comfort is significantly improved when using the AVC in comparison to the timer, showing up to 50% improvement in acoustic comfort for periods of moderate office activity according to the criteria used in this study.

If the higher limit of the AVC is set to 48 dBA instead of 45 dBA, according to the criteria used in this study, then speech privacy will be improved by up to 15% in comparison to the timer function, without any significant reduction of the acoustical comfort.

6 REFERENCES

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