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Liveliness as a design parameter for open plan offices

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ABSTRACT

Human activity is crucial regarding the sound level in open plan offices. However, design and evaluation standards such as ISO 3382-3, as well as most measurements in office environments, do not take into account how much noise is being produced or acceptable to receive in actual work situations. The Liveliness index - classifying sound environments as 'Quiet', 'Tranquil', 'Lively' or 'Turbulent' - aims to fill this gap.

Different types of work come with different requirements for, or sensitivity to sound production. Using a high density sensor grid, the Liveliness method allows for accurate sound activity measurements specific to each type of work present in a certain organisation. Combined with room acoustical parameters, these can be used as a design tool, indicating the desired privacy or nuisance distances specific to the types of work that characterise an organisation. Such dedicated design helps avoiding discomfort and productivity loss. Since the method uses descriptions rather than decibels to qualify the sound environment, communication with people unfamiliar with acoustics is also simplified. This paper suggests how to use Liveliness as a design input, and summarises our recent experience applying it in different office environments.

Keywords: human activity, design tool, zoning

1. INTRODUCTION

Noise is considered one of the most significant causes of discomfort and productivity loss in open plan offices. The perceived level of discomfort increases when the noise level in an office rises (1), but the sound pressure level (SPL) itself barely affects performance (2,3). When it comes to productivity, the presence and loudness of intelligible irrelevant speech is more important. It causes distraction, which results in loss of performance in a number of common office tasks, particularly those involving word processing (4–6). The second most important source of distraction is the sound of ringing phones, followed by machine noise and the sounds of people walking by (7–9).

This means that human activity in the office is by far the most important reason for office employees to experience discomfort and productivity loss. Designers and consultants involved in the development of such office environments therefore have a great responsibility to carefully consider their required room acoustical quality and the spatial layout. ISO 3382-3:2012 proves to be a useful guideline in this context, but not one without limitations. Excluding human activity from the measurements benefits their accuracy, but as a consequence the results are not entirely representative to qualify the room acoustical quality of an open plan office in use, which is the very reason to determine the quantities described in ISO 3382-3 in the first place.

Activity Based Working, which has become a standard way to design open offices, incorporates a variety of possible activities. As demonstrated by Vellenga-Persoon et. al., sound levels also differ significantly between office types (10). Every organisation and type of work has its own requirements with regard to silence, liveliness and privacy. To adequately design an open office with acoustical properties that fit the organisation that uses it, additional information is required that can qualify the way in which that organisation would use its office.

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2. Assessing room acoustical quality in open offices

2.1 ISO 3382-3

To quantify the room acoustical quality of an office room or area, ISO 3382-3:2012 describes a number of measurements with which a set of single number quantities can be determined. These quantities, intended for describing the degree of sound propagation and predicted level of distraction, are most importantly:

- spatial decay rate of speech SPL ($D_{2,S}$);
- SPL of speech at 4 meters, ($L_{p,A,S,4m}$);
- background noise level, ($L_{p,A,B}$);
- speech transmission index, (STI);
- distraction distance (r_D);
- privacy distance (r_P).

A large $D_{2,S}$ means that the sound level will drop quickly when moving away from the source. $L_{p,A,S,4m}$ is derived from $D_{2,S}$ assuming a normalised speech SPL. Both quantities can be used to determine the expected loudness of a sound source (normally a speaking person) at a certain distance. Looking at speech transmission in a more detailed way, the Speech Transmission Index (STI) in comparison does not predict how loud a voice will be at a certain distance, but how much of it is being transmitted in an intelligible way. This can be used to determine how many words, sentences or sounds of a speaking person can be understood at the receiving end. The distance from a speaker at which STI = 0.50 is described as r_D. At this distance, roughly 90 % of sentences can be understood (4). Only when STI decreased to 0.2, almost no sentences can be understood anymore. This is considered r_P.

Since the intelligibility of irrelevant speech is one of the main sources of distraction and productivity loss, STI is an important quantity to predict the room acoustical quality. ISO 3382-3 considers any STI above 0.50 to impose a risk of distraction. This value corresponds with values reported by Hongisto (4), who predicts a performance loss up to 7 % in situations with an equal or greater STI. For difficult tasks, the performance loss may even increase up to 11.5 % (6). Using the STI, also the privacy distance and distraction distance can be calculated.

The abovementioned quantities, as well as reverberation time, are commonly used to predict the room acoustical quality of a space, although they are not necessarily representative for an office in use. In fact, the standard specifically prescribes that the measurements have to be carried out when people are absent. Acoustic conditions with people talking are explicitly not part of its scope. All of the abovementioned quantities do however, to a certain extent, depend on the way in which the room is being used. Most office employee working in an open office will only use their work environment while other people are present. This is especially true for offices that have been designed to accommodate Activity Based Working (ABW). ABW involves a variety of activities located on one office floor, sometimes within the same space, each creating and demanding its own acoustical environment. A critical part of information about the use of the office is therefore missing in the assessment, when relying solely on ISO 3382-3.

The background noise level for example, is defined as the SPL when no people are present, caused by e.g. road traffic noise, sound masking and building services. As mentioned earlier, the noise level influences the perceived comfort. It is uncertain whether constant noise remains a source of discomfort over time, as several researchers report signs of habituation (7,11), while others claim that these effects cannot be found except in laboratory studies (5,9). Fluctuating sounds are considered to cause distraction and therefore discomfort, as they require a short period of reorientation (3). The sound level in an office space and especially its variation is normally caused by people, meaning that the most important aspects of background noise can only be measured when the office is being used.

Measurement of the STI requires input about the real use as well, as it is based on, among other quantities, a predefined speech SPL and the background noise level. Whether or not the predefined speech SPL is applicable to an office, cannot be determined without carrying out measurements while the office is being used. Also the background noise of traffic and ventilation systems may be irrelevant compared to the background noise produced by (distant) speech. Consequently, STI will also not be as reciprocal as measurements in an empty office may suggest. It is not hard to imagine that speech from someone engaged in a lively phone call will be better intelligible to someone doing quiet, focussed work than the other way around. Accurate predictions of the STI while the office is being used, can therefore not be made without collecting additional data that is specific to the office in question. By extension, this applies to the distraction distance and privacy distance as well.

Also when using the speech to noise ratio (SNR) to predict distraction, both the actual speech SPL and the actual noise level need to be known, in order to make an informed prediction about the present quality. This issue is recognised by Harvie-Clark and Larrieu (12), who propose the use of a matrix that describes a SNR specific to the type of sending and receiving function. Depending on a higher or lower expectation of noise production and sensitivity to noise, a higher or lower SNR is proposed.

2.2 Liveliness

To qualify the sound environment and summarise the average activity level and its fluctuation, Vellenga et al. (13) coined the term Liveliness. It is based on a linear numerical scale called the MACH Index (MI), ranging from 1 (very quiet) to 10 (very turbulent). Intended as an instrument to make a sound environment understandable also to laymen who might find decibels vague and hard to understand, Liveliness categorises a sound environment as one of four possible options: Quiet (MI = 1.0-2.0), Tranquil (MI = 2,5-5.0), Lively (MI = 5.5-8.0) and Turbulent (MI = 8.5-10.0).

Liveliness and MI are based on the equivalent sound level during five minutes $L_{\mathrm{A,eq,5min}}$ as well as the degree of sound fluctuation. The latter has been defined as the difference between the aforementioned equivalent SPL, and its fifth percentile during the same period $L_{\mathrm{A5,5min}}$. Using the assessment matrix described in (13), both quantities are added up, leading to a MACH Index, which corresponds to a certain degree of Liveliness as described above. Through several questionnaires, this score has been verified to correspond with the average subjective perception of a sound environment.

Liveliness varies over time and between working stations. For a useful qualification of a sound environment, which is not affected by temporary exceptions (e.g. holidays, or more employees doing home office on a certain day), Liveliness will have to be monitored during longer period of time, which has to be at least several weeks. Growing opportunities that originate from rapid advances with regard to the Internet of Things make it possible to monitor sound levels on a large scale at relatively low cost, using a network of sensors that are installed at a representative amount of work stations.

The Liveliness score can then be used as a means of communication with other people involved in the design process, indicating to which extent the Liveliness of the area or room corresponds with the intended use. An architect that sees that a certain area qualifies as ‘Lively’ over 70 % of the time, while it is supposed to accommodate silent and focused work, will immediately understand that measures need to be taken to make the office space fit its purpose. Reporting a histogram of measured sound levels is far less likely to have the same result. These sound levels will still remain available to the acoustical consultant of course, to be used as detailed input in the consulting process, e.g. in combination with $D_{2,\mathrm{S}}$ or STI.

2.3 Non-physical measures

Not every measure has an effect that can be quantified using measurements as described in ISO 3382-3. When for example a call centre is being equipped with better headsets, this has no effect on the spatial decay rate, or reverberation time. The reduction of the sound level in that space, as well as the need for this reduction, can only be quantified by measuring the actual human activity in that room.

Furthermore, psychological processes or behavioural guidelines may influence a sound environment in ways that are not reflected by the degree physical changes. Where the Lombard effect explains how the SPL rises exponentially when people start to speak louder in a loud room, the reverse is also true. Adding sound absorption to a room results in a decreased SPL, due to which people lower their voice and an even greater reduction is achieved. Measurements of reverberation time alone cannot explain this, but measurements of the degree of Liveliness will clearly show the change. Finally, changes in behaviour (such as walking to a designated area when receiving a phone call) will show a difference in Liveliness, without displaying any change of room acoustical qualities measured according to ISO 3382-3.

Examples like these illustrate why Liveliness as a result of human activity cannot be ignored when designing and improving open office environments.

3. In situ monitoring of Liveliness and SPL

3.1 Method

Since the development of MI and the corresponding Liveliness, M+P have implemented as a consulting tool in several office buildings. The data gathered during these measurements and the subsequent insights, are summarised in this chapter. Figure 1 shows a selection of the physical environment at several of the measurement locations.

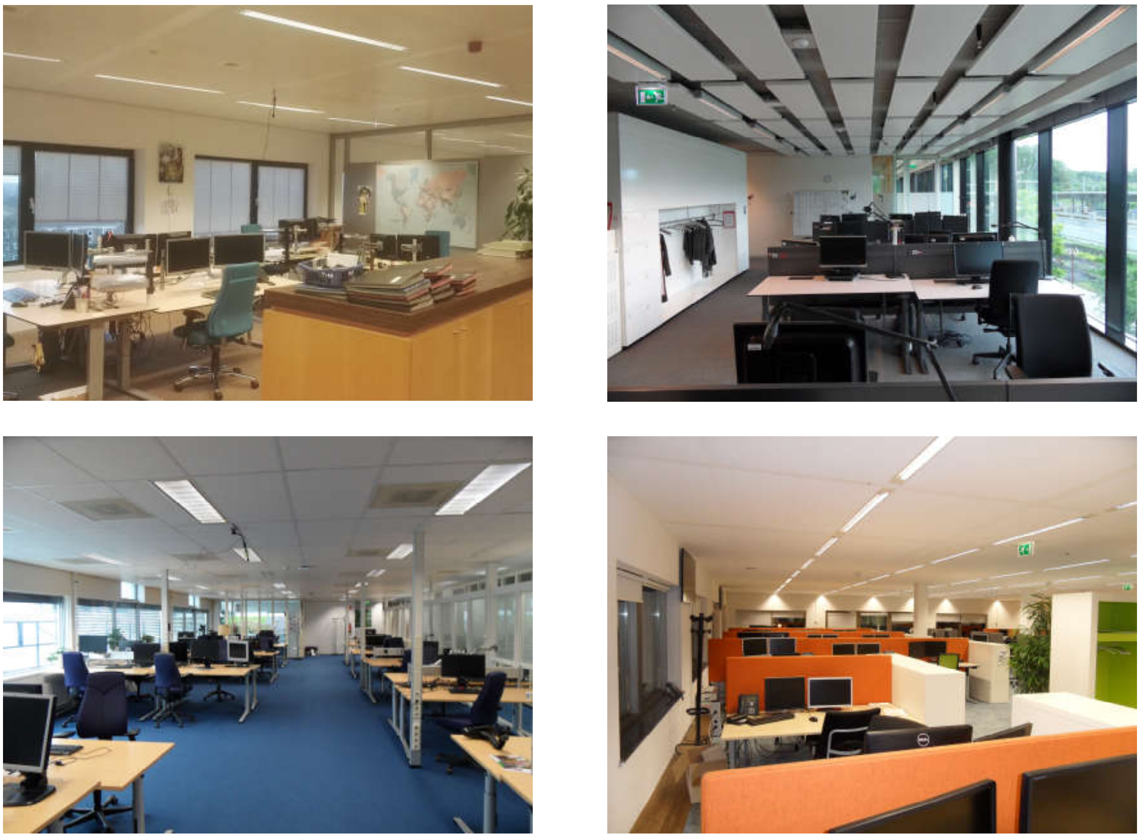

Figure 1 – impression of a number of office environments mentioned in this paper, clockwise from left top: bank, government, telecom, wholesale

This paper describes data from a total of 18 sensors, distributed over six different office buildings, where they gathered data for a period that varied between several weeks and more than a year. All measurements were carried out in the Netherlands, on office floors that were designed with ABW in mind. Usually a mixture of activities took place within the same space. Some of the measurement locations were in call centres, however most were situated on an open office floor. This paper emphasizes on the data obtained on regular open office floors (14 sensors, four buildings). For equal comparison, only the data measured on weekdays between 09.00 – 17.00 hours has been considered.

3.2 Measurement data

The measurement data and the corresponding conclusions serve as illustration to the examples of how to use Liveliness as a design tool, which is described in the following chapter.

3.2.1 Average Liveliness and MACH Index

The average MACH Index on all open office floors that were part of this research, has been summarised in figure 2. The first bar of the box plot shows significantly lower Liveliness values than the other examples, which is due to unexpected lower occupancy of this office space. Although because of that, this cannot be qualified as a typical office space, it has been included to illustrate that also the absence of human activity can be input for design.

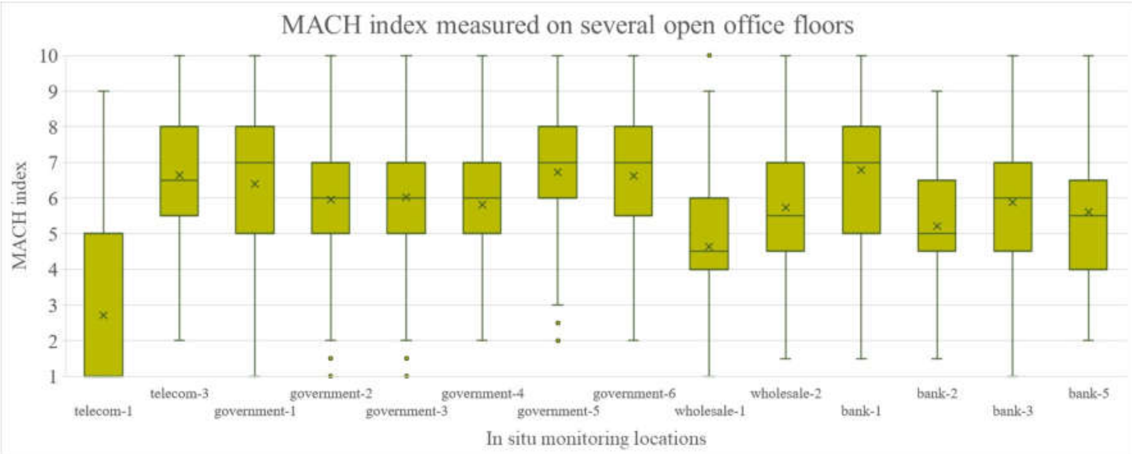

Figure 2 – Distribution of MACH Index for all measured open office environments (excluding call centres), displayed per sensor (x = mean value, • = outlier)

Other bars display a difference between the 1st and 3rd quartile of the MACH Index of 2-3 points. All sensors display a maximum between MI = 9 and MI = 10 ('Turbulent'), and a minimum between MI = 1 and MI = 2 ('Quiet'). The 1st and 3rd quartile values are all within the range of MI = 4 ('Tranquil') and MI = 7 ('Lively'). The median shows fairly wide range, varying from 4.5 to 7. When ignoring 'telecom-1', the average MACH Index on these floors was MI = 6 with a standard deviation of 0.6. Table 1 shows the average MI and the corresponding standard deviation. In general, the data shows that an open office environment in the Netherlands requires at least brief monitoring of the sound environment to fit the desired purpose, due to the fairly large difference in MACH Indices between office floors. Should for a certain reason in situ measurement not be possible, a MACH Index of 6 (which only just corresponds to 'Lively') can be used as a starting point, since based on these measurement data MI = 6.0 seems to fit the average office environment.

Table 1 – Average MACH Index and standard deviation per sensor located in an open office environment

sensor	average MI	SD	sensor	average MI	SD
telecom-1	2,7	2,39	government-6	6,6	1,74
telecom-3	6,6	1,66	wholesale-1	4,6	1,78
government-1	6,4	2,37	wholesale-2	5,7	1,75
government-2	6,0	1,44	bank-1	6,8	2,07
government-3	6,0	1,31	bank-2	5,2	1,57
government-4	5,8	1,44	bank-3	5,9	1,75
government-5	6,7	1,68	bank-5	5,6	1,58

The Dutch guideline NPR 3438:2007 EN describes a target and maximum equivalent SPL threshold for several types of work, among which 'using a computer in an office environment'. An equivalent SPL that does not exceed 45 dB(A) is considered ideal for an office floor, while a SPL higher than 55 dB(A) should disqualify it to be used as such. Figure 3 shows how often the sound environment at each sensor location qualifies as a certain Liveliness category, and how often the abovementioned thresholds are being exceeded. The added value of including these thresholds can be seen when comparing e.g. B3 and B5, which have an almost equal distribution of Liveliness categories, as well as a very similar average SPL, but at B3 the target value is exceeded 39 % of the time, compared to 89 % for B5. Based on this, B3 should be suitable for focused work substantially more often than B5.

The maximum threshold is rarely exceeded at any of the measurement locations.

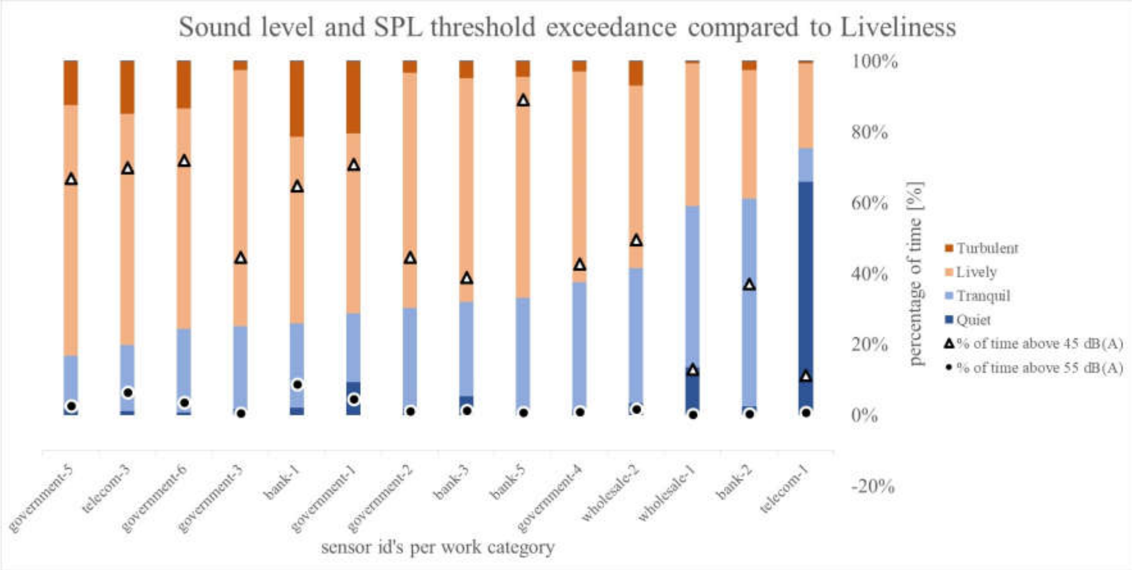

Figure 3 – Percentage of time [%] during which the sound environment at each measurement location qualifies as a certain Liveliness category, as well as the percentage of time during which the SPL was higher than 45 dB(A) and 55 dB(A), respectively.

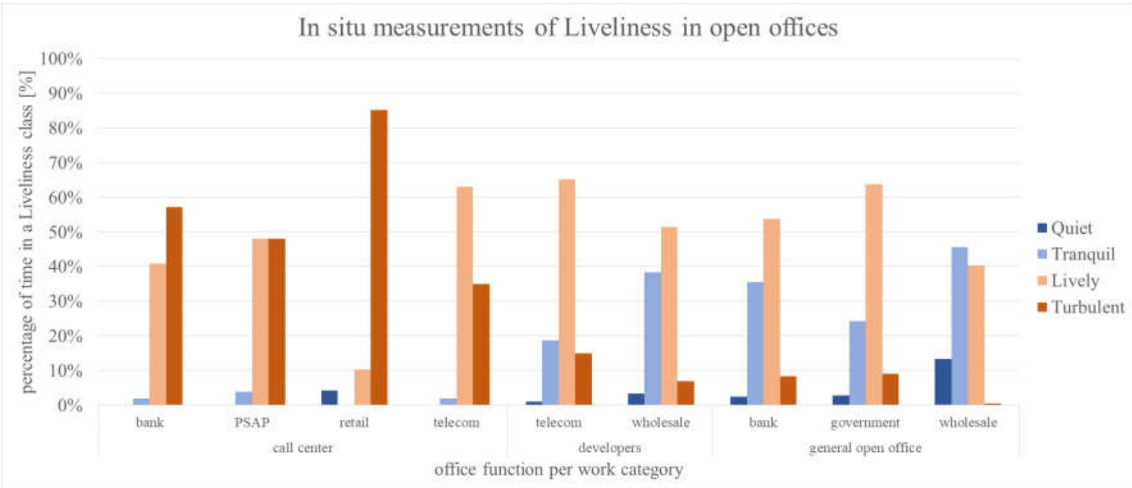

Figure 4 – Average percentage of time [%] during which the sound environment at each measurement location (including call centres, excluding telecom-1) qualifies as a certain Liveliness category

As shown in Figure 4, call centres generally impose a risk of turbulent sound environments, but there is a big difference between the measured locations, implying that a different design or use can have a considerable influence on the amount of turbulence.

4. Using Liveliness as a design tool

To inspire and illustrate the potential of including Liveliness measurements into the design process for new or renovated open offices, we share real examples from our consulting praxis in which Liveliness proved to be useful.

4.1 Sound environment within a work cluster

When redesigning a call centre with a retail function, that was located in a room of 7 by 7 meters, the measurements in the original situation revealed an almost continuously turbulent work environment (70-80 % of the time). Considering the intention to almost double the number of employees from 6 to 11, it was evident that as many measures as possible had to be taken to even slightly improve the situation. A better absorbing ceiling was introduced, as well as highly absorbing wall panels and desk screens. Since the reverberation time decreased from 0.4 seconds to 0.3 seconds, one would expect an increase of the average SPL of 1-2 dB(A), taking into account that the number of employees doubled. The measurement in the new situation showed a decrease of 1-2 dB(A) instead, proving the effectiveness of a new behavioural code. After the renovation the percentage of time that the sound environment qualified as 'Turbulent', increased to approximately 90 %. This can be explained by the higher fluctuation of the sound level after increasing the number of employees.

4.2 Communication of measures based on the current sound environment

Before the redesign of a large investment bank, measurements were carried out at multiple office spaces, one of which accommodated the service desk. In the original design, most office areas were separated from each other by enclosed meeting rooms. To improve connectivity between different areas, these rooms were removed in the new design, and also the planned separating wall placed around the future service desk was initially not approved by the client. The measurement results at the present service desk, showing a turbulent sound environment over 57 % of the time, and virtually no 'quiet' or 'tranquil', helped the architect to convince the client however that this wall should not be excluded. The easy-to-understand semantics of the Liveliness method helped parties that are not acoustical professionals to communicate about sound in a meaningful manner, leading to a crucial change in the client's attitude. The fact that the MACH Index is limited to a maximum of 10, while sound levels can theoretically increase indefinitely, helps to put the measured data in perspective.

4.3 Qualifying the effect of a renovation

While measurements prior to a renovation or redesign can provide useful input to quantify the specific needs of the organization in question, this also represents an ideal situation where the consultant is invited to the design process while the process of refurbishing has not yet taken place. Also after introducing measures, measurements can be a helpful support to the design process, verifying whether the intended quality has been reached. Monitoring in a large 24/7 Public Safety Answering Point (PSAP) proved that employees had reason to not be satisfied with the sound environment. Monitoring on four locations proved that the two central work clusters were far louder than the ones towards both ends of the room, causing disturbance to the employees working in the quieter areas. Liveliness was an easy instrument to show the main sources of noise in the PSAP.

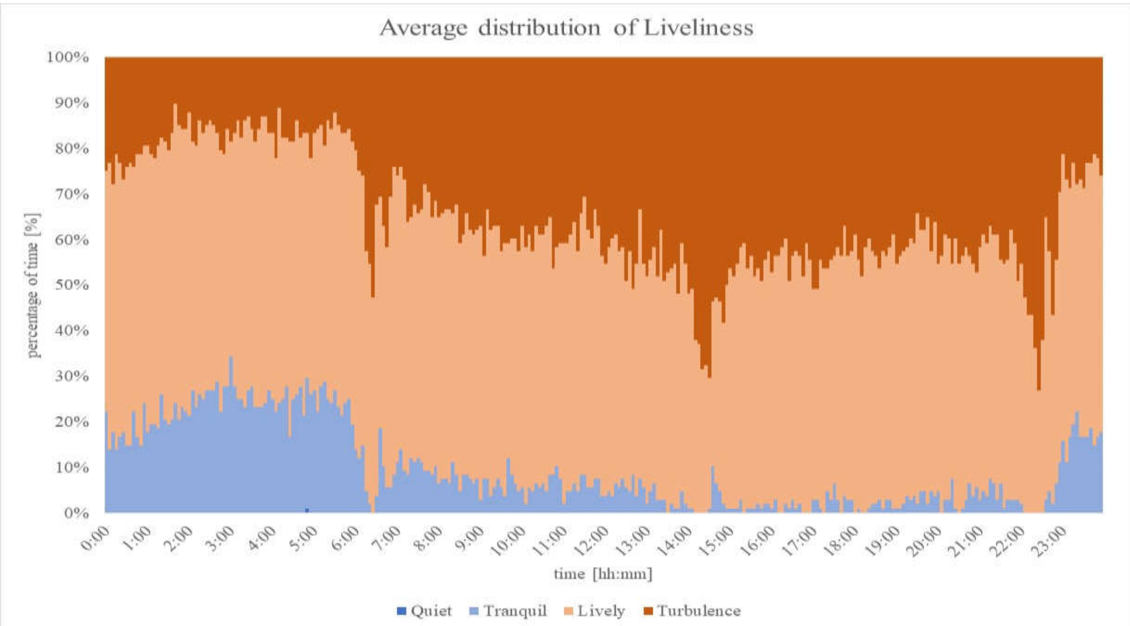

Figure 5 – Heat map of the average Liveliness for four sensors per five minutes of the day, averaged over all measured days during one month, showing the variation in Liveliness throughout the day.

Furthermore, problems within the work clusters were addressed. Fast communication is crucial in a PSAP and this concept was highly valued in the design, but the consequential idea of each cluster having to contain a mixture of police, fire brigade and ambulance employees proved to be counterproductive, as certain professions required more frequent and more intense phone conversations than others.

Finally, the liveliness measurements were able to address behaviour that caused a turbulent sound environment. Figure 5 displays the average distribution for all sensors, averaged over every measured day, showing the Liveliness distribution per five minutes of the day. Three peaks in the turbulent sound environment are evident, at 6:30, 14:30 and 22:30. These times were quickly matched to the moments at which shift changes take place, and helped encouraging more quiet shift changes to respect those that are still or already working.

5. CONCLUSIONS

ISO 3382-3 offers a set of quantities which are a good starting point for the assessment of room acoustical quality of open plan offices. It still lacks input about the actual use however, which is needed to properly calculate most of the respective quantities and put them in the right perspective. Since every user has its characteristic requirements for the sound environment, which also varies over time and between locations, monitoring the SPL at a number of representative locations for multiple weeks is necessary to determine how lively a certain office area is. Since the design process involves many parties, several of which may not be familiar with the acoustical jargon, a means to avoid the use of decibels will increase the communicative strength of the acoustical engineer's message. The Liveliness method is proposed as such a tool. The combined use of room acoustical quantities from ISO 3382-3, SPL monitoring data and the Liveliness index will lead to acoustical design that is easier to explain and fits better with the intended purpose of the open plan office in question.

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