Applied Acoustics 228 (2025) 110324

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Acoustic comfort in primary- and nursery-school canteens: From measurements to recommendations ☆

Francesco Martellotta [a,*], Dario D'Orazio [b], Deborah De Carolis [a], Stefania Liuzzi [a], Chiara Rubino [a]

[a] Politecnico di Bari, Department of Architecture, Construction, and Design, via Orabona, 4, Bari, 70125, Italy
[b] University of Bologna, Department of Industrial Engineering, viale del Risorgimento, 2, Bologna, 40136, Italy

ARTICLE INFO

Keywords:
Acoustic comfort
Primary schools
Vocal effort
Intelligibility
Room acoustics
Eating establishment
School canteen
Nursery

ABSTRACT

Canteens usually have critical acoustic conditions resulting from the need to maximize the number of occupants while minimizing volume. Thus, in the absence of specific sound absorbing treatments, very high sound pressure levels are usually observed resulting in significant impairment of communication (with increased vocal effort of speakers and reduced speech intelligibility), and dangerously high exposure levels for workers. The present paper reports acoustic measurements carried out in a nursery school canteen having a volume of 212 m^3 and seating about 50 children, and two primary school canteens having volumes of 656 m^3 (seating 150 children) and 367 m^3 (seating 107 children). Reverberation time was measured in each room as well as sound pressure levels during peak occupation (averaged over 15-minute intervals), resulting in A-weighted sound pressure levels spanning between 81 dB (in the nursery school) and 90 dB in the primary schools. Starting from the observed values, considerations about the group-size of the occupants as a function of age were made, and recommendations were finally given to guide the acoustic correction of similar spaces.

1. Introduction

The role of room acoustics in schools and teaching spaces has been largely investigated in recent years, leading to important results both in terms of research and practical regulations. In Italy, in particular, after the publication of design guidelines for schools [1] a specific National Standard has been recently issued [2] and its use is now mandatory as a consequence of building code [3]. School canteens, although being partly included in such regulations, are usually less investigated in the scientific literature, certainly because they are used for shorter time intervals and they do not affect teaching (and learning) processes. However, it is indubitable that they play an important social role, as students may more easily talk and interact among them while having often significant impacts on workers attending the students' activities. The literature on eating establishments has received important contributions that pointed out the role of background noise control and room acoustics to limit the Lombard effect [4–8], also leading to the definition of more specific criteria to explain and assess the acoustic requirements of such spaces [9]. Regarding canteens, previous studies investigated university or college canteens [10,7,11,12], but a few results can be found about primary or nursery school canteens, usually in more generic studies [13,14]. Other studies on the acoustics of eating establishments have been carried out recently, but they focused on how acoustics affects comfort and behaviour [15,16], food quality perception [17,18], willingness to spend time and money in restaurants [19], and the effect played by other factors like ageing [20,21] and pathological conditions [22].

However, school canteens are peculiar spaces, where most of the above-mentioned factors play a marginal role: cost and quality of food become less relevant factors. Moreover, the age of the occupants is significantly lower, and it is related to preserving hearing capacity in a more sensitive category. Conversely, other aspects become more important and need to be carefully taken into account, like the higher occupant density, due to the need to maximize space use in a limited time [23], or the higher exposure levels for workers [24].

The present paper reports the results of acoustic measurements carried out in selected spaces where the number of occupants was very

☆ This is an extended version of the paper "A Field Survey of Acoustic Conditions in Primary and Kinder School Canteens" presented at Forum Acusticum 2023, 11-15 September 2023.

* Corresponding author.
E-mail address: francesco.martellotta@poliba.it (F. Martellotta).

https://doi.org/10.1016/j.apacoust.2024.110324
Received 15 April 2024; Received in revised form 6 September 2024; Accepted 25 September 2024
Available online 1 October 2024

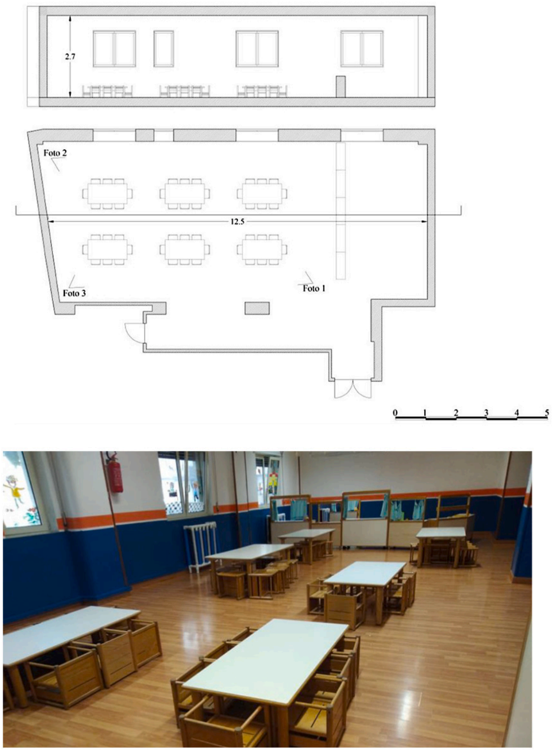

Fig. 1. Plan, cross-section and interior view of nursery school canteen (N1).

high compared to the volume and critical conditions were found for booth pupils and workers.

2. Methods

2.1. Case studies

Three canteens located in Bari were investigated, one belonging to a nursery school (N1) attended by 1 to 5-year-old pupils, one belonging to a primary school that also offered support to a nursery school (P1), and one serving only a primary school (P2). The first one (Fig. 1) has a floor surface area of 78.5 m^2, a net height of 2.7 m, and an overall volume of 212 m^3. The number of pupils that can be seated is 50, resulting in a volume per person of 4.24 m^3/pers. Walls and ceilings are plastered and no other furniture apart from small tables and seats is in the room. The floor is made of laminated wood.

The second canteen (P1) is a simple rectangular room (Fig. 2) having a floor surface of 243 m^2, a net height of 2.7 m, and a volume of 656 m^3. The maximum capacity is 150 pupils, resulting in a volume per person of 4.37 m^3/pers. Even in this case walls and ceiling are plastered and the floor is finished in ceramic tiles. No furniture, carpets or curtains are in the room apart from tables and seats.

The third canteen (P2) is an L-shaped room (Fig. 3), having a floor surface of 136 m^2, a net height of 2.7 m, and a volume of 367 m^3. The maximum number of seated occupants is 107, resulting in a volume per person of 3.43 m^3/pers. The walls and ceiling are finished in plaster, and the floor is finished in hard polished stone. No furniture is in the room. A summary of the main geometric and acoustic features of the three spaces is given in Table 1.

2.2. Measurement protocol

Two different sets of measurements were carried out in each room. First, room acoustic measurements were carried out under unoccupied conditions, measuring impulse responses according to ISO 3382-2 [25]. All the specifications prescribed for "engineering" method were used.

Fig. 2. Plan, cross-section and interior view of the canteen in primary school P1.

Table 1
Summary of the main geometric and acoustic quantities observed in the selected spaces: V = room volume (m^3), N = maximum number of occupants, A_0 = overall absorbing area under unoccupied conditions (500-2000 Hz) (m^2).

ID	V	N	V/N	A_0	A_0/V	A_0/N	S_f/N
N1	212	50	4.24	20.3	0.096	0.41	1.57
P1	656	150	4.37	29.7	0.045	0.20	1.62
P2	367	107	3.43	22.7	0.062	0.21	1.27

With reference to sound source, instead of using an electro-acoustic source, complying with directivity limits set by ISO 3382-1 [26], for practical reasons balloon bursts were used to excite the rooms. As the major limitation resulting from using balloons is related to a difficult-to-control directivity pattern, particularly at low frequencies, for each source-receiver combination two impulse responses were recorded, taking care to carefully randomize the point of impact at every burst to limit repeatability issues due to directionality. In any case, as the measurements were aimed at determining the reverberation time, directivity issues were not considered to be a problem. Impulse responses were recorded using a pair of omnidirectional microphones (Soundman OKM II), worn by one of the authors and connected to a Tascam DR08 portable recorder. Post-processing and acoustical parameters calculations were made using Matlab scripts. Reverberation time was calculated considering a 20 dB decay to ensure that a proper signal-to-noise ratio was available across the whole frequency range of interest. In each space, at least two source positions were used and three receiver positions.

The second set of measurements was carried out under fully occupied

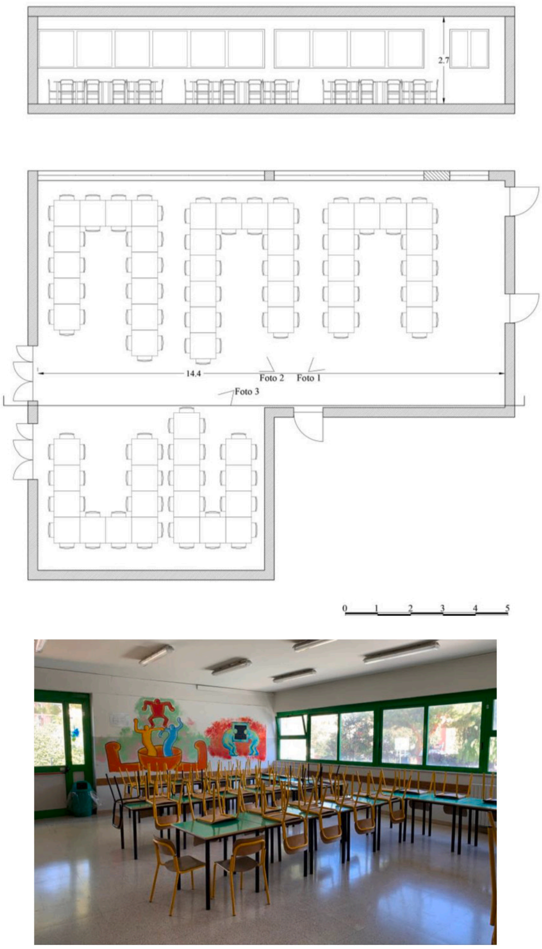

Fig. 3. Plan, cross section and interior view of the canteen in primary school P2.

conditions when lunch was served. In this case, a calibrated 01 dB SOLO sound level meter equipped with a GRAS 40AR random incidence microphone was used. The sound level meter was mounted on a tripod during the measurements, in a central position located at least 2 m from any direct sound source. Measurements covered the whole lunchtime, arranged in 15-minute recording sessions, including entrance, eating, and exiting phases. In case of P1 two consecutive shifts were considered, in order to characterize sound levels generated by both nursery school and primary school pupils. One-third octave band levels (mean, minimum and maximum), statistical levels, and overall A-weighted level were determined.

2.3. Subjective survey

In addition to objective measurements, a simple questionnaire was administered to three classes of the two primary schools (two in P1 and one in P2). The questionnaires were presented to fourth and fifth graders only, during normal lesson time, under the supervision of the teachers, after a brief introduction about noise and sound was given, and explaining that they were aimed at evaluating their acoustic perception in the school canteen during lunch time. Responses were collected anonymously and only if the participants wanted to participate. Questions were limited in number and presented in the form of five-point ordinal scales with descriptors and visual aids (in the form of emoticons) to better match the descriptor with the question (Fig. 4). Questions were aimed at investigating: 1) the quality of hearing other students seated at the same table; 2) the quality of hearing other students seated at the other tables; 3) annoyance due to noise; 4) hearing and understanding teachers and assistants. In addition, questions with dichotomous

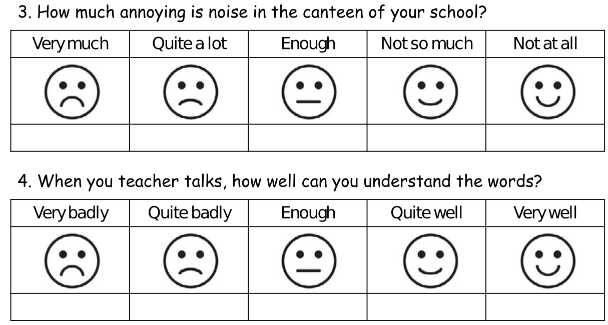

Fig. 4. An excerpt from the questionnaire survey.

answers (yes/no) were finally presented to investigate: 1) if they perceived too much noise; 2) if they felt quiet after spending time in the canteen; 3) if they had problems hearing the teacher after the lunch service; 4) if they felt angry or irritated after lunch. Results of the questionnaires were not used to explore correlations with noise levels, as they were not collected in the same space and at the same time as the measurements, but only helped to understand the impact that canteen noisiness may have on the general perception of the students.

2.4. Modelling sound pressure levels in spaces with several speaking occupants

To discuss results and evaluate suitability of the analyzed spaces, it was interesting to take advantage of the model proposed by Rindel [27] to express the A-weighted ambient noise level $L_{N,A}$ as a function of the number of simultaneously speaking occupants (N_S), the overall absorbing area in the room (A), and the A-weighted sound power level for one person speaking ($L_{W,A}$)

$$L_{N,A} = L_{W,A} + 10\log N_S - 10\log(A/4) \quad (1)$$

The number of simultaneously speaking occupants is calculated by dividing the total number of occupants N by the "group size" g (i.e. the number of persons per speaker, usually a number between 3 and 5).

The A-weighted sound power level for a speaking person is, on the other side, dependent on the background noise according to the Lombard effect which states that:

$$L_{S,A,1m} = 55 + c(L_{N,A} - 45) \quad (2)$$

where $L_{S,A,1m}$ is the A-weighted sound pressure level at 1 m from the mouth of the speaker and c is the Lombard slope, describing the increase in level resulting from every dB background noise exceeding the 45 dB threshold (below that value people are assumed to speak normally without increased effort). According to several studies as collected by Lazarus [28] c varies between 0.5 and 0.7 (Table 2). So, considering the speaker as a point source with a directivity index of 3 dB, it is possible to combine Eq. (1) and (2) to obtain:

$$L_{N,A} = \frac{1}{1-c}(69 - 45c + 10\log N_S - 10\log A) \quad (3)$$

From Eq. (2) it is also possible to derive the signal-to-noise ratio (SNR) given by $L_{S,A,1m} - L_{N,A}$, according to which it can be shown that:

$$SNR = 10 - (L_{N,A} - 45)(1 - c) \quad (4)$$

So, if c is assumed to be 0.5, SNR is 10 dB under optimal conditions (i.e. $L_{N,A} \leq 45$ dB), and then decreases to 0 dB when $L_{N,A} = 65$ dB. In addition, Eq. (3) can be used to derive the "acoustic capacity" of a room with an overall absorption A, defined as the maximum number of occupants allowed in the room for "Sufficient" quality of verbal communication, where the latter is achieved when signal-to-noise ratio is ≥ -3 dB within a distance of 1 m. As previously said the number of occupants is related to the number of speakers by means of the "group

Table 2
Group-size values found in previous studies.

Ref.	Environment	Lombard slope c	Group-size g
Tang et al. [10]	university canteen	double slope[1]	–
Hodgson et al. [29]	university canteen	0.7	3
Rindel [27]	restaurants	0.5	3-4
Pinho et al. [13]	primary / nursery canteens	0.4	2
Devos et al. [20]	nursing homes	0.5	8
D'Orazio et al. [30]	museum	0.4	4
Wang et al. [11]	university canteen	–	4-8[2]
Calia et al. [12]	university canteen	0.5	8[3]

[1] $L_{A,N} > 69$ dB was the threshold value; [2] the value increase with ambient noise; [3] restrictions due to the COVID-19 pandemic applied.

size" g. As shown in Table 2, g is dependent on different factors, and, in a noisy canteen with densely packed occupants is likely to be close to the lowest values. Based on these assumptions, the acceptable level can be calculated as the value that ensures at least a SNR of −3 dB, or a $L_{N,A}$ of 71 dB, often rounded off to 70 dB to provide some extra margin.

To understand the best strategy to improve the conditions in spaces like those under investigation, Eq. (3) points out the essential role of overall absorption A, assuming that the number of occupants is often difficult to modify due to lack of space and need to optimize time for lunch which force to exploit the maximum possible seating capacity. In rooms with no extra sound absorption, the major contribution to A is given by the occupants. A is given by the sum of the absorption in the unoccupied room $A_0 = 0.16 \cdot V/T_0$ (where V is the room volume and T_0 the reverberation time), and due to the occupants $N \cdot A_p$, where A_p is the extra absorption per person that depends on frequency, posture (seated or standing), clothing and age. Literature provides several alternative values for A_p [31,32] but, to account for the A-weighted level returned by the formula, a value between 0.3 and 0.5 m^2 is usually adopted, depending on seat typology, clothing and age of the occupants [27]. Considering the age of the occupants, in the subsequent part the smaller value will be used. Finally, assuming $c = 0.5$ and expliciting the group-size parameter g, it is possible to determine $L_{N,A}$ as a function of occupants number and room absorption.

$$L_{N,A} = 2\left[46.5 - 10\log g - 10\log\left(\frac{0.16V}{T_0 N} + A_p\right)\right] \quad (5)$$

Anyway, the case with no extra absorption is a limiting case, mostly found in existing spaces, while for new or refurbished spaces standards provide a minimum value of absorption. Italian standard UNI 11532-2 [2] defines design criteria for acoustical optimization of schools and, regarding canteens, it prescribes a minimum absorbing area (under unoccupied conditions) given by:

$$A/V \geq [2.13 + 4.69 \cdot \log(h/1)]^{-1} \quad (6)$$

where h is the room height and the calculation needs to be performed for all the octaves from 250 Hz to 2000 Hz.

3. Results

3.1. Reverberation times

Measured reverberation times (T_{20}) showed quite different values among the surveyed canteens (Fig. 5), basically as a consequence of their volumes. In fact, P1 showed the longest T_{20}, followed by P2, and N1. Some scattering in the measured values appeared, as expected, in the lowest frequency bands, but the variations were generally small. Calculating the mean absorption coefficient, by taking into account actual volume and total surface area, returned a value varying between 0.04 and 0.05 for P1 and P2, and slightly higher, equal to 0.07, for N1, possibly because of the different seats and tables (Fig. 1).

Taking into account the procedures explained in UNI 11532-2 standard [2] it was possible to compare the measured values against the

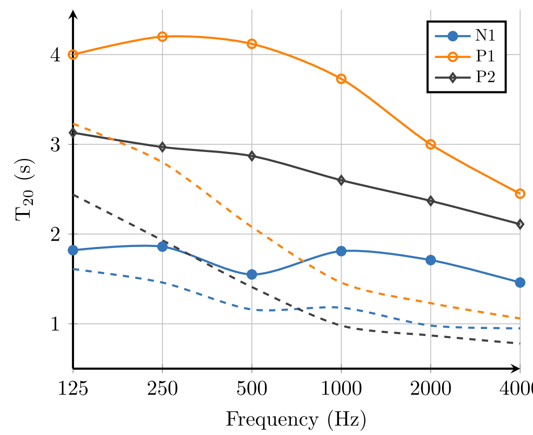

Fig. 5. Reverberation time (T_{20}) as a function of frequency in the three canteens surveyed, measured under unoccupied conditions (–) and predicted under full occupancy with Sabine's formula (- -).

optimal values suggested for category A.6.4 (including canteens and bars). Considering the height of 2.7 m, for all the rooms the limiting A/V ratio should be greater than 0.240 m^{-1} using Eq. (6). Taking into account the measured T_{20} and the volume of each canteen, the average ratio among the octaves is 0.09 m^{-1} for N1, 0.04 $m^{-1}$for P1, and 0.06 m^{-1} for P2. Thus, it is largely below the desired value, as recommended by the standard, suggesting that a significantly larger amount of sound-absorbing treatments would be needed.

Based on the measured T_{20} values and on the volume of each room, it was possible to calculate, using the methods proposed by Rindel [9], assuming generically $c = 0.5$ and $g = 4$, the acoustic capacity of each space, resulting in 6.3, 8.4, and 6.7 persons, respectively for N1, P1, and P2. As the acoustic capacity is defined as the maximum number of persons in a room allowing sufficient quality of verbal communication, such values confirm that the spaces are far from being suitable for use by the expected number of pupils.

Using the equivalent absorption per person given in the standard [2], it was also possible to calculate the predicted values of the reverberation time under fully occupied conditions. These values were calculated using Sabine formula, assuming an ideally diffuse sound field. However, based on the amount of absorption due to occupancy, resulting in a mean absorption higher than 0.1, Eyring formula might have been more appropriate but, given the lack of scattering elements on the walls and the ceiling, and the concentration of absorbing elements only on the floor, it is likely that non-diffuse behaviour may take place and longer reverberation times might be observed in practice.

3.2. Sound pressure levels

Concerning sound pressure measurements, Fig. 6 shows the time histories for the three selected spaces and, for P1, for two different occupancy conditions. It can be observed that, during lunchtime, the short L_{eq} (calculated regarding a 2 s time interval) varies within a rel-

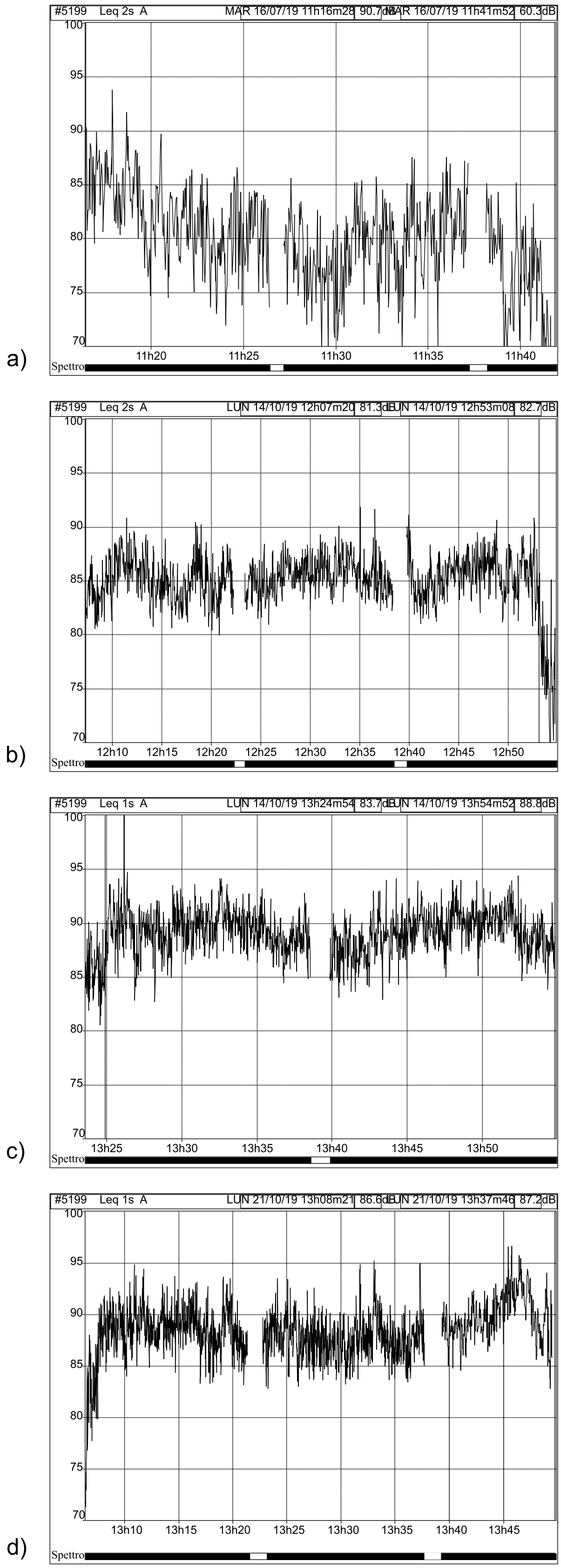

Fig. 6. Time histories recorded in the three surveyed canteens: a) N1, b) $P1_N$, c) $P1_P$, and d) P2.

atively narrow range (about 10 dB) in all the cases. Only in the N1 case, a larger variation is observed, with a maximum (around 90 dB) at the very beginning (pupils entering the space and taking place), and a slight decrease of around 70 dB toward the end of lunchtime when the first classes started to exit the space. In the primary schools, the levels remained more stable around 80 and 90 dB in P1 during the first shift when nursery school pupils were in the room (later on referred as $P1_N$), and around 85 and 95 dB in P1 during the second shift when primary school pupils, mostly 4th and 5th graders were in the room (later on referred as $P1_P$), and P2. The averaged $L_{N,A}$ over the entire measurement period were 81.4 dB, 84.9 dB, 89.9 dB and 89.2 dB, respectively for N1, $P1_N$, $P1_P$, and P2. The maxima observed in the four cases were 95.4 dB, 95.9 dB, 97.6, and 99.5 dB respectively. The lowest levels were observed in N1, where the overall number of occupants was smaller in combination with higher absorption per person (A_0/N) resulting in the lowest reverberation time. The loudest levels were found in $P1_P$ and P2 cases. The latter was expected because the volume per person and the floor surface per person were the lowest compared to the others. However, to explain the similarity in $L_{N,A}$ between the second shift in P1 and P2, despite different volume and occupancy, it was interesting to observe that both P1 and P2 shared the same absorbing area per person (Tab. 1). Conversely, the 5 dB variation between the first and second shift in P1 could be certainly explained as a function of a slightly lower occupancy in the first case (with about 80% of the seats actually occupied), but, as it will be better discussed later, this variation was not sufficient to justify such a reduction in level, which was likely to be related to an increased group size, as suggested in Table 2.

In terms of spectrum, Fig. 7 shows that the three average spectra were relatively similar and overlapped, with a significant rise between 200 Hz and 5 kHz, clearly related to the specific characteristics of the voices of the small occupants. In case of P2, it was observed that maxima exceeded 80 dB up to 12.5 kHz, while in the other cases, a steeper fall was observed. This was realistically related to the much more compact arrangement of tables and, as already stated, the lower volume per person. In terms of minima, it is worth noting that N1 showed the lowest values, likely as a consequence of the reduction of the occupants during the last part of the measurement period, as demonstrated by the similarity with background noise spectra. In fact, the shape of the spectrum remained similar, with the voice-related peak appearing in the 200 Hz - 5 kHz range. Despite exposure time is relatively limited, the observed values may represent a serious issue for pupils and workers. Similar values were only found in one case by Cotana et al. [14] in the canteen with the highest occupancy.

3.3. Questionnaires

Regarding subjective responses (see Table 3), 48 questionnaires were collected in P1 and 21 in P2. Concerning the intelligibility between students seated at the same table, in P1 they were symmetrically distributed around the centre value, while in P2 the distribution was skewed towards the lowest grades, with a strange 19% of responses stating very good intelligibility. Moving to the intelligibility of speech between students seated at different tables, most of the responses, more or less equally distributed, were distributed among ratings from 1 to 3, suggesting a very hard time understanding what is said at other tables. Ratings were very similar concerning the intelligibility of the teacher or other operators, with 81% of negative evaluation (1-2) in the case of P2. It is worth pointing out that no one rated intelligibility as "very high" in both schools for the last two questions. Finally, concerning noise annoyance, coherently with previous results, in P1 61% of the responses were equal to three or higher, while in P2 the percentage raised to 86%, with a 24% of very highly annoyed. Despite a relatively uniform distribution of ratings among the various categories, it is interesting to point out that when asked if there was too much noise in the canteen, 96% of the interviewees in P1 and 100% in P2 answered "yes". This might be explained as a consequence of the difficulty of quantifying their sensations, while

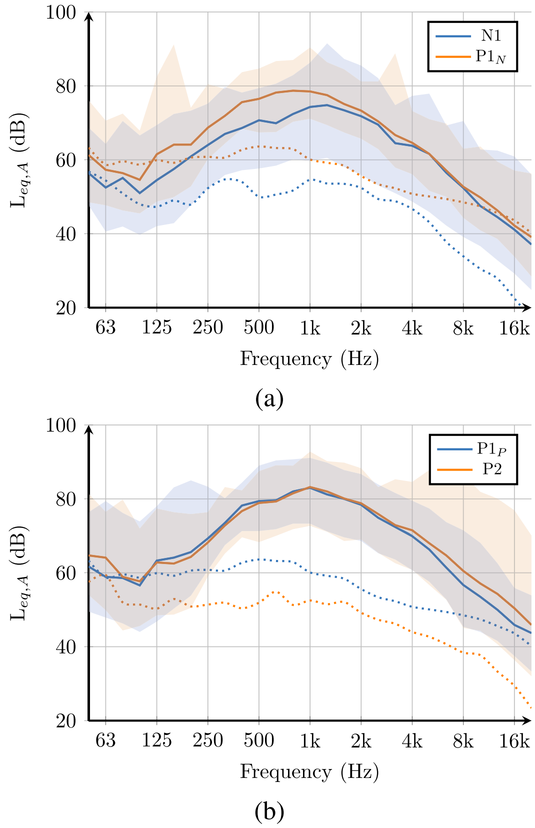

Fig. 7. One-third octave band spectrum calculated over the entire measurement time in the three surveyed canteens (shaded areas represent minimum-maximum range), compared to background levels (dotted curves) measured before lunch time. a) Canteen N1 and P1, with nursery school pupils; b) Canteens P1 and P2 with primary school students.

Table 3
Percent distribution of subjective ratings (1 = very low, 5 = very high), pertaining to the different questions.

	Rating				
	1	2	3	4	5
	Same table intelligibility				
P1	5	27	36	27	5
P2	5	48	19	9	19
	Other table intelligibility				
P1	30	45	15	11	0
P2	29	33	33	5	0
	Teacher intelligibility				
P1	13	33	40	14	0
P2	38	43	14	5	0
	Noise annoyance				
P1	10	29	31	23	7
P2	0	14	38	24	24

the simple and direct question required a more direct (and easy to provide) answer. Despite such a high number of dissatisfied, it is good to observe that 73% of the students in P1 and 67% in P2 felt quiet once they got out of the canteen, suggesting that the remaining part (about one-third) was not. Coherently, 19% of respondents in P2 and 12% in P1 had problems hearing the teacher (once in the classroom), and 8% in P1 and 14% in P2 even felt angry or irritated after spending time in the canteen. Such results confirm what the measured sound pressure levels already suggested, with nearly all of the occupants of the canteens being dissatisfied and significant percentages of them declaring short-term auditory (difficulty in hearing) and non-auditory (feeling upset or angry) effects that certainly raise concerns.

Table 4
Measured and predicted noise levels $L_{N,A}$ due to speech in the three spaces under investigation, as a function of different occupants.

ID	Measured	Pred. (g = 4)	g_{adapt}	Pred. (g_{adapt})
N1	81.4	83.6	5	82.0
$P1_N$	84.9	86.7	5	84.3
$P1_P$	89.9	87.5	3	89.5
P2	89.2	87.2	3	89.4

3.4. Analysis of acoustic capacity and corrective measures

The observed results clearly raise some concerns about exposure limits for both children and school workers who operate in canteens. According to World Health Organization [33] the maximum daily exposure level to prevent hearing loss is set to 70 dB, resulting from a weekly exposure of 80 dB for a maximum of 40 hours. For sensitive listeners like children, such limit is further reduced by 5 dB [34]. Thus, the weekly sound allowance for children exposed to 85 dB is reached after 5 hours, which reduce to 1 hour and 15 minutes if the level rises to 90 dB. For adults, the weekly limit with the latter level is reached after 5 hours of exposure. Consequently, While for the nursery school (N1) the situation seemed not critical (also considering that the lunchtime for each class is about 30 minutes), for primary schools where mean L_{eq} approaches 90 dB, some sort of corrective action is needed to reduce risks of hearing damage. In addition, under these critical conditions, the possibility to communicate (and consequently the social value of eating together) was severely impaired and apart from subjects seated closely, the conversation was impossible and many children remained isolated. Observation during the measurements also showed that some of the pupils were protecting their ears with their hands when they were not eating.

To this purpose, starting from the formulas discussed in Sec. 2.3, it was possible to first check their validity and then investigate the amount of sound absorption that should be applied in the space to make them usable for a large number of users or, vice versa, to define the acoustic capacity corresponding to each room configuration.

It was interesting to observe that, without any correction and using actual occupancy values, the predictive formula (Eq. (5)) returned values close but not exactly equal to measured values (Table 4). In particular, it appeared that values were overestimated when the occupancy was made of nursery pupils, while it was underestimated when the space were occupied by primary school pupils. As hypothesized in the analysis of the differences appeared in P1 between the two shifts, it is reasonable to assume that the younger occupants tend to interact less among them (and site observation actually confirmed this), increasing the group size, while the primary school pupils were more sociable and this reduced the group size. By assuming adapted values of 5 and 3, respectively for the younger and older occupant groups, the new predicted $L_{N,A}$ values became 82 dB and 84.3 dB for N1 and $P1_N$, and 89.5 dB and 89.4 dB for $P1_P$ and P2. A better agreement could be obtained by adding decimals to g values, but given the limited sample, an approximation based on integer numbers was considered sufficient.

That proposal is not properly a model calibration carried out over a range of occupancy and relative $L_{N,A}$ as a function of occupancy N. However, it should be considered that in school canteens, occupancy is almost always constant: children enter and exit simultaneously. This indeed justifies the rather regular trend of ambient noise levels: the standard deviation between $L_{N,A}$ values is less than 2 dB for measurements taken during meal times, and the value is a bit higher for the nursery, as one might expect. Values further from the average occur at the beginning and end of the service, when children enter or exit the environment. Moreover, the measured values fall within a saturation region

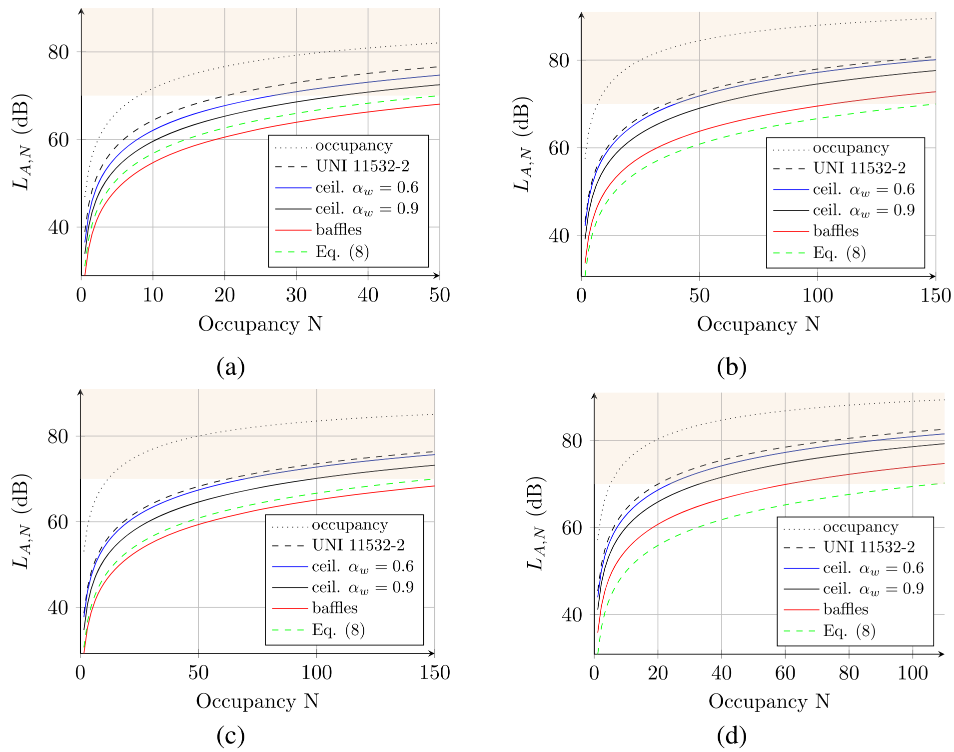

Fig. 8. Predicted sound pressure level as a function of ceiling treatment and occupants' number in a) nursery school N1, b) Primary school P1 $g = 3$, c) Primary school P1 $g = 5$, d) Primary school P2.

of the predictive model, as they are well above 75 dB(A). To have significant variations in ambient level, we would need substantial variations in occupancy, which is not possible in school canteens for the reasons mentioned above. The (contained) variations in ambient noise levels can, therefore, be attributed to the natural behaviour during meal service and the behaviour of the talkers. It should be noted that in this region, the Lombard Effect equation used in ISO 9921 (which is the basis of the Rindel model) can lose generality: the group size may increase because some children may intentionally choose to remain silent [12], or the Lombard slope may have a dual slope [21].

Starting from this adjustment in the formulas, considering that the ceiling is the only surface that in, all of the cases, is free to be treated, in the subsequent discussion its surface was supposed to be covered with different materials, having different absorption coefficients.

- The baseline treatment was derived from UNI 11532-2 standard [2] with particular reference to Eq. (6). The difference between the minimum absorbing area and that already existing in each space (under unoccupied conditions), was added.
- The whole ceiling was supposed to be covered by a "medium absorbing" treatment with $\alpha_W = 0.6$.
- The whole ceiling was supposed to be covered by a "highly absorbing" treatment with $\alpha_W = 0.9$.
- The whole ceiling was supposed to be covered by highly absorbing baffles, capable of doubling the actual absorbing area, compared to the previous case.

As shown in Figs. 8a and 8b baffles were the only way to achieve acceptable acoustic conditions while keeping the number of occupants as high as it is currently. Acoustic capacity (Table 5) dropped significantly for all the other solutions that were investigated, including the one based on minimal recommended values based on national standards which allows comfortable conditions for a fraction of the whole capacity, depending on g values (Fig. 8b, c). Regarding case P2 (Fig. 8d) the situation was even worse, because, being the room with the lowest volume per person, even using the baffle treatment the acoustic capacity reached a maximum of 61 persons, but remained significantly below the maximum usual occupancy. As this room was the one with the lowest floor surface per person, this result suggested that optimal absorption needs to be adapted accordingly, to account for denser occupant distributions.

Table 5
Predicted acoustic capacity relative to the three spaces under investigation, as a function of different absorption treatments: Occup = occupants only, UNI = minimum according to UNI 11532-2 (A.6.4), Baff. = baffles covering whole ceiling.

ID	Occup.	UNI	$\alpha_w = 0.6$	$\alpha_w = 0.9$	Baff.
N1	8	20	25	35	$> N_{max}$
P1 (g = 5)	12	61	70	98	$> N_{max}$
P1 (g = 3)	7	36	39	57	110
P2	5	20	24	33	61

4. Discussion

The absorption suggested by UNI 11532-2 standard, although significant, may be considered satisfactory only in terms of noise exposure, because, even in case of full occupancy, $L_{N,A}$ remains below 80 dB, which ensures, even in case of a daily exposure of one hour, a weekly average of 65 dB, which is below the recommended limit. However, in terms of verbal communication and vocal effort, the resulting absorption does not seem to be enough for spaces like school canteens where many seats are packed in a relatively small space. In fact, rearranging Eq. (3) and Eq. (6) as a function floor area per person, assuming $c = 0.5$ and $g = 4$, it yields:

$$L_{N,A} = 81 - 20\log\left(\frac{S_f h/N}{2.13 + 4.69\log h} + A_p\right) \quad (7)$$

Where S_f is the floor area. So, it can be observed that the 70 dB value results from a floor surface of about 5 m^2 per seat, which seems

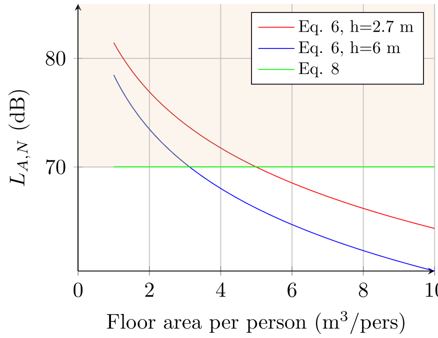

Fig. 9. Comparison of predicted sound pressure level as a function of floor area per person, obtained using Eq. (6) and Eq. (8).

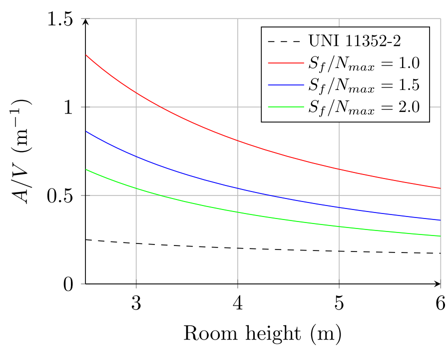

Fig. 10. Plot of overall absorption per room volume A/V as a function of room height and minimum floor area per person (S_f/N_{max}).

a little bit too generous even for fine-dining restaurants where a maximum of 2 m^2 per person is usually considered as a design criterion, which reduces to 1 m^2 per person in case of fast-foods and canteens. In the present cases the floor area per person spans between 1.3 and 1.6 m^2/pers, thus, to ensure good acoustic comfort, a much higher absorbing area than that recommended by Eq. (6) is needed, as demonstrated by results obtained when baffles were used for acoustic treatment. To compute the absorption that is necessary to get the 70 dB target, Eq. (7) was reworked to obtain a final $L_{N,A}$ of 70 dB, and, by normalizing the expected absorbing area as a function of room volume, and introducing the minimum floor area per person (given by S_f/N_{max}), so that the extra absorption can be better adapted to the characteristics of each space, a new formula is proposed, yielding:

$$A/V \geq \left(\frac{14.12}{g} - A_p\right)[(S_f/N_{max})h]^{-1} \tag{8}$$

As shown in Fig. 9, the new formula allows to obtain $L_{N,A}$ values that are independent of the minimum floor area per person (resulting from the maximum occupancy) and of the room height, thus providing acceptable acoustic comfort in terms of verbal communication under the most severe conditions and even better conditions if the occupancy is lower than 100%. Fig. 10 compares A/V ratios resulting from Eq. (6) and those resulting from Eq. (8) with different S_f/N_{max} ratios, showing that in spaces with high ceilings, the value converges but remains up to three times higher for the lowest S_f/N_{max}, while in case of lower (normal) ceiling height, the new suggested values may be up to five times higher than those given by Eq. (6).

It is interesting to point out that, at least in extreme cases like those analyzed in this paper, using Eq. (8) to compute the requested absorption yields $L_{A,N}$ values that change very slowly as a function of occupancy, meaning that small changes in the desired $L_{A,N}$ values can cause a large change in acoustic capacity. However, from a different point of view, this also means that there is a large tolerance both in terms of occupancy and absorption needed. In fact, Eq. (8) was obtained by assuming

Table 6
Target acoustic capacity relative to the three spaces under investigation, and relevant absorbing area (A_{req}) resulting from Eq. (8), together with variations in occupancy and absorbing area resulting from adoption of a $L_{N,A}$ of 71 dB instead of 70 dB.

ID	Acoustic capacity [persons]	ΔN [persons]	A_{req} [m^2]	ΔA_{req} [m^2]
N1	50	+7	126	–15.2
P1 (g = 5)	150	+20	378	–45.5
P1 (g = 3)	150	+20	661	–75.9
P2	110	+15	484	–55.7

a 70 dB target, which, if relaxed to 71 dB, may on one side require a reduced amount of absorption (variation given as ΔA_{req} in Table 6), or, in case the requested absorption (A_{req}) is employed, allow for a significant variation in the number of occupants (up to 20 for case P1).

5. Conclusions

The paper investigated the acoustical conditions in three canteens located in a nursery school and in two primary schools, one of them also offering service to a nearby nursery school. In all of them, the combination of reduced volume, high occupation density, and long reverberation time, caused sound pressure levels to become dramatically high during lunchtime. The averaged $L_{eq,A}$ over the entire measurement period were 81.4 dB, 84.9 dB, 89.9 dB, and 89.2 dB, respectively for N1, P1 with nursery pupils, P1 with primary school pupils, and P2. Comparison with current health-protection standards showed that while in the first case the exposure levels are less critical, in the others they require much more attention. With reference to acoustic comfort and speech intelligibility, all the cases require more absorption to be installed in the room to ensure that lower levels may be achieved during service hours. After a critical discussion of the requirements stated by current standards, considering the limited height of the spaces that were investigated, an improved formula was proposed to provide acceptable acoustic comfort while taking into account group size, occupation density, and actual room height.

CRediT authorship contribution statement

Francesco Martellotta: Writing – review & editing, Writing – original draft, Visualization, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Dario D'Orazio:** Writing – review & editing, Writing – original draft, Visualization, Validation, Formal analysis. **Deborah De Carolis:** Writing – review & editing, Visualization, Investigation, Data curation. **Stefania Liuzzi:** Writing – review & editing, Investigation, Formal analysis, Data curation. **Chiara Rubino:** Writing – review & editing, Investigation, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The authors are grateful to the Director of "Circolo Didattico n. 14 Re David" Prof. Sabatina Aresta, and the Director of the "Simpatiche Canaglie" nursery Dr. Marta Montrone, for kindly granting access to the spaces during activities.

References

[1] Astolfi A, Garai M. Linee guida per una corretta progettazione acustica di ambienti scolastici. Roma, Italy: Associazione Italiana di Acustica; 2017.

[2] UNI 11532-2, Caratteristiche acustiche interne di ambienti confinati – Metodi di progettazione e tecniche di valutazione – Parte 2: Settore scolastico. Milan, Italy: UNI; 2020.

[3] Decree of Italian Ministry of Ecological Transition, 23 giugno 2022 n. 256, on "Minimum environmental criteria" ("Criteri ambientali minimi per l'affidamento del servizio di progettazione di interventi edilizi, per l'affidamento dei lavori per interventi edilizi e per l'affidamento congiunto di progettazione e lavori per interventi edilizi").

[4] Webster JC, Klumpp RG. Effects of ambient noise and nearby talkers on a face-to-face communication task. J Acoust Soc Am 1962;34:936–41.

[5] Marsico G, Brambilla G, Curcuruto S, Clapiz M, Betti R, Riccardi M. Acoustic climate inside a canteen and mitigation solutions. In: Proc. of Acoustics'08 Paris; 2008. p. 5217–21.

[6] Hodgson M, Razavi Z, Steininger G. Evaluation of acoustical environments in eating establishments. Build Acoust 2009;16:125–48.

[7] Zelem L, Chmelík V, Urbán D, Rychtárikova M. Analysis of the acoustic conditions in the student restaurant. In: Proc. of euronoise 2015; 2015. p. 1627–31.

[8] Chen X, Kang J. Acoustic comfort in large dining spaces. Appl Acoust 2017;115:166–72.

[9] Rindel JH. Suggested acoustical requirements for restaurants, canteens, and cafeterias. In: Proc. of Baltic-nordinc acoustic meeting 2015; 2018.

[10] Tang SK, Chan DWT, Chan KC. Prediction of sound-pressure level in an occupied enclosure. J Acoust Soc Am 1997;101:2990–3.

[11] Wang C, Kong X, Yao S, Kang J, Yuan J. Crowd noise and vocal power level in large college canteens in China. Appl Acoust 2021;182:108242.

[12] Calia G, Puglisi GE, Shtrepi L, Riente F, Bottalico P, D'Orazio D, et al. Validation of predictive algorithms for the estimation of the number of people in a canteen. In: Forum acusticum; 2023.

[13] Pinho PG, Pinto M, Almeida RMSF, Lemos LT, Lopes SM. Aspects concerning the acoustical performance of school cafeterias. Appl Acoust 2018;136:36–40.

[14] Cotana F, Asdrubali F, Arcangeli G, Luzzi S, Ricci G, Busa L, et al. Extra-auditory effects from noise exposure in schools: results of nine Italian case studies. Acoustics 2023;5:216.

[15] Meng Q, Zhang S, Kang J. Effects of typical dining styles on conversation behaviours and acoustic perception in restaurants in China. Build Environ 2017;121:148–57.

[16] Tarlao C, Fernandez P, Frissen I, Guastavino C. Influence of sound level on diners' perceptions and behavior in a Montreal restaurant. Appl Acoust 2021;174:107772.

[17] Woods AT, Poliakoff E, Lloyd DM, Kuenzel J, Hodson R, Gonda H, et al. Effect of background noise on food perception. Food Qual Prefer 2011;22:43–7.

[18] Fiegel A, Meullenet JF, Harrington RJ, Humble R, Seo H-S. Background music genre can modulate flavor pleasantness and overall impression of food stimuli. Appetite 2014;76:144–52.

[19] Bottalico P. Lombard effect, ambient noise, and willingness to spend time and money in a restaurant. J Acoust Soc Am 2018;144(3) EL209-214.

[20] Devos P, Aletta F, Thomas P, Vander Mynsbrugge T, Petrovic M, Van de Velde D, De Vriendt P, et al. Application of a prediction model for ambient noise levels and acoustical capacity for living rooms in nursing homes hosting older people with dementia. Appl Sci 2020;10:4205.

[21] Bottalico P, Piper RN, Legner B. Lombard effect, intelligibility, ambient noise, and willingness to spend time and money in a restaurant amongst older adults. Sci Rep 2022;12:6549.

[22] Lebo CP, Smith M, Mosher E, Jelonek S, Schwind D, Decker K, et al. Restaurant noise, hearing loss, and hearing aids. West J Med 1994;161(1):45–9.

[23] Ghozi R, Fraj O, Salem MBH, Jaidane M. Occupancy-based analysis and interpretation of soundscape auditory complexity: case of a campus restaurant. J Acoust Soc Am 2015;63(6):475–87.

[24] Alnuman N, Altaweel MZ. Investigation of the acoustical environment in a shopping mall and its correlation to the acoustic comfort of the workers. Appl Sci 2020;10:1170.

[25] ISO 3382-2, Acoustics – measurement of room acoustic parameters – part 2: reverberation time in ordinary rooms. Geneva, Switzerland: ISO; 2008.

[26] ISO 3382-1, Acoustics — measurement of room acoustic parameters — part 1: performance spaces. Geneva, Switzerland: ISO; 2009.

[27] Rindel JH. Verbal communication and noise in eating establishments. Appl Acoust 2010;71:1156–61.

[28] Lazarus H. Prediction of verbal communication in noise – a review: part 1. Appl Acoust 1986;19:439–64.

[29] Hodgson M, Steiniger G, Razavi Z. Measurement and prediction of speech and noise levels and the lombard effect in eating establishments. J Acoust Soc Am 2007;121:2023–33.

[30] D'Orazio D, Montoschi F, Garai M. Acoustic comfort in highly attended museums: a dynamical model. Build Environ 2020;183:107176.

[31] Kath U, Kuhl W. Messungen zur schallabsorption von personen auf ungepolsterten stuhlen [Measurements of sound absorption of audience on unupholstered seats]. Acustica 1964;14:49–55.

[32] Martellotta F, Della Crociata S, d'Alba M. Laboratory measurement of sound absorption of occupied pews and standing audiences. Appl Acoust 2011;72(6):341–9.

[33] World Health Organization. Environmental noise guidelines for the European region, Geneva; 2018.

[34] World Health Organization and International Telecommunication Union. Safe listening devices and systems: a WHO-ITU standard, Geneva; 2019.