**Article title:** Application of transparent microperforated panel to acrylic partitions for desktop use: A case study by prototyping

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(Cover letter to the revised version)
18 June 2021

Dear Editor

We are pleased to submit the revised version of the manuscript entitled as 'Application of transparent microperforated panel to acrylic partitions for desktop use: A case study by prototyping,' for a possible publication as an open commentary in UCL Open Environment.

We are grateful for the reviewers' constructive comments. Below is the summary of the revision in this version. The text added or amended sentences in the manuscript are marked in red fonts.

[To the comments from Simone Torresin]

*Thank you very much for your positive and constructive comments. Although the reviewer does not require an amendment, the comments encouraging for the future study are suggested. We consider that they are important for this paper to mention the points of future studies. Thus, we added the sentences below:*

In the last paragraph of Section 3, we added:

*For this purpose, a parametric study with perforation ratio, hole diameter, etc, will be needed both in theoretical and experimental method.*

In the last paragraph of Concluding remarks:

*For this purpose, a parametric study both in theory and experiment will be necessary. Particularly, a theoretical model analysis will be helpful for a practical design.*

With these sentences, we can clarify the points of future studies which we actually are planning. Thank you very much.

[To the comments from Tin Oberman]

*Thank you very much for constructive and detailed comments on our paper. Although this review is structured in the style of an article, in the following, the response to the comments is summarised in point by point style.*

I found that the application of transparent microperforated panels as acoustically enhanced social distancing tool is a very useful idea in the times of a pandemic and potentially beyond. It would be also very useful to find out how much worse acoustically do the standard acrylic partitions make the spaces they are added to and to what extent can the microperforated ones mitigate the issue without introducing significant reduction in visual transparency and significant increase in costing.

*Thank you very much for this positive appreciation. Many people have experienced changes in the acoustic environment caused by a desktop partition such as the one discussed here, but little concrete data has been published. There are studies by Sugie et al. [12, 13] on the effect of partitions on sound transmission, but to the authors' knowledge there is no data on the effects on room acoustics. It would be ideal if we could measure these effects and add the results, but this research covers the presentation of the idea and up to the sound absorption measurement test of the prototypes: we are firstly investigating whether it is possible to create a transparent partition with sound absorbing properties. Therefore, it remains to be seen to what extent sound-absorbing partitions using an MPP can actually have an effect on the acoustic environment in a room, however, if the partition is placed over a certain area, it can be easily expected that a sound-absorbing effect will appear. These limitations of the present study are mentioned in the text of Concluding remarks.*

Moreover, it would be useful to understand how this prototype visually and acoustically compares with the commercially available solutions such as the Clearsorber (RPG). While some of these answers might be beyond this particular study, I believe they are important to bear in mind while reporting the results and writing concluding remarks so to make them as useful for further research as possible. I found the text to be overall clear and easy to read. However, there is still room to improve the structure and the clarity. As there is no other content than the absorption measurements, I would suggest making the report even more robust to ensure reproducibility. While the main message is easy to understand, English language would need to be improved as well.

*Clearsorber (RPG) is designed to be large in size and to have a larger air-back layer, therefore, it cannot be applied directly for the present purpose. The sound-absorbing performance of RPG is better than one we proposed here: about 0.3-0.5 in NRC and higher than 0.5 at peak absorption coefficient. It is a pioneer product as MPP with transparency. From the point of view of its intended use, Clearsorb is not designed for the application of our study, but it is an innovative commercial product of transparent MPP. The webpage of this product is cited as a reference [8] of a pioneer product of transparent MPPs in Introduction. A brief comparison was made in Appendix using the published data. We expect that this will give some idea.*

*Regarding English language, the manuscript has been edited by a professional English editing service, however, this time we have proofread the text carefully to make it readable.*

Regarding the structure, the section 3 should be made more efficient. Please reorganise this section and report the experiment in a more technical and less narrative manner. For instance, the Figures 5 and 7 are obsolete, all the data needed is visible in the Figure 9. The distinction between the experiments 1 and 2 is currently not clear. It reads as it is about one experiment with four different levels of intervention into the original panel (no intervention, two microperforated panels added, adhesive tape added, adjustments made to add acrylic seals). If so, please adjust the structure accordingly.

*As pointed out, it is appropriate and clear to consider this point as one experiment. However, based on the results of the experiment, the final specification of the prototype was decided through a trial and error process in three steps. For this reason, we do not refer to the experiments as Experiment 1 and Experiment 2, but describe each study as a series of experiments, such as Step 1, Step 2 and Step 3. This is because we did not compare the experiments under the three conditions from the beginning, and by describing them step by step, we can make the findings from the series of experiments clearer. In addition, we would like to leave the figures as they are, although there is some duplication of information. This is because it makes clearer the problems and their solutions at each stage.*

I believe the middle panel is the key feature in the light of the epidemiological measures which motivated this study so I would suggest moving the explanation behind that specific design trait to the introduction and including it in the abstract (by expanding the existing sentence and stating the reason for having the non-perforated droplet barrier in between).

*The existing text at the end of the Introduction has been changed to a more detailed description and this has also been added to the Abstract.*

For the purpose of the reproducibility, please report more data related to the experiment and in accordance with the ISO 354, i.e. the surface area of the 10 panels, the reverberation time without any panels inside, number of measurement points used in measurements, measuring equipment etc. Perhaps there is a paper published with a more detailed description of that very room and measurement system you could simply refer to?

*Some more detailed information about the measurement settings, including arrangement of the specimens, surface area of the specimens, etc, are now added.*

Moreover, adding a supplementary datasheet with the exact measured absorption values would potentially help further research that could look into modelling the potential effect of such panels on noise levels or indoor soundscape.

*As suggested, a table of the numeric data for Specimen (c) is given in Appendix, as a supplementary* *datasheet.*

How was the target sound absorption frequency range decided?

*We have targeted the main frequency bands of speech (mid-frequencies), but due to the nature of sound absorbers, we have not covered all of them completely.*

Figure 3 could be horizontally arranged so it takes less space.

*The figure is now arranged horizontally, as suggested.*

Figure 4 is not completely clear. Would it be possible to add better pictures that show the whole of the panel so the background does not get in the way of understanding the details and so it is clear how the panel is standing, i.e. is it touching the floor or not. While the Figure 2 is clear in that regard, the other photographs are ambiguous. The size of the 'legs' might not be that important for absorption, but I can see no reason not to report it. The same goes for the details about the joints and if any dampening materials were used anywhere in the design. Also, a figure showing the visual effect of combining small and large holes would be useful to understand the influence of perforations and extra layers on the overall visual transparency.

*It was difficult to take a clear photograph as the specimens were transparent, however, in this revision, we replaced some of photographs with better ones. The size of the 'legs' are now added in the caption of Figure 2, which is 120x80 mm made of 5 mm thick acrylic sheet. Some photographs include the images of the joints. As is observed in figures, we did not use any damping materials. Even when we cannot provide better photo/picture, we added necessary information in the text or the captions.*

More references could be added to the introduction or some less important paragraphs featuring very general and not-referenced statements could be omitted.

*Thank you for your advice. Due to the nature of the journal, we have tried to include some general information to make it more accessible to non-acousticians. We cite a book suitable for general readers in Introduction. However, we did not omit the existing paragraphs, because we believe that a certain amount of general content is better to be included for a general reader, please understand.*

Overall, this is brief, clear and concise paper, hopefully leading to further studies and application

*Thank you very much for your detailed review. We hope that this revision meets your scientific standard.*

Application of transparent microperforated panel to acrylic partitions for desktop use: A case study by prototyping

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ABSTRACT
There are various measures currently in place to prevent the spread of COVID-19; however, in some cases, these can have an adverse effect on the acoustic environment in buildings. For example, transparent acrylic partitions are often used in eating establishments, meeting rooms, offices, etc., to prevent droplet infection. However, acrylic partitions are acoustically reflective; therefore, reflected sounds may cause acoustic problems such as difficulties in conversation or the leakage of conversation. In this study, we performed a prototyping of transparent acrylic partitions to which a microperforated panel (MPP) was applied for sound absorption while maintaining transparency. The proposed partition is a triple-leaf acrylic partition with a single acrylic sheet without holes between two MPP sheets, as including a hole-free panel is important to a possible droplet penetration. The sound absorption characteristics were investigated by measuring the sound absorption in a reverberation room. As the original prototype showed sound absorption characteristics with a gentle peak and low values due to the openings on the periphery, it was modified by closing the openings of the top and sides. The sound absorption performance was improved to some extent when the top and sides were closed, although there remains the possibility of further improvement. This time, only the sound absorption characteristics were examined in the prototype experiments. The effects during actual use will be the subject of future study.

Keywords: transparent desktop partition; transparent microperforated panel; sound absorption; COVID-19

1. Introduction

The COVID-19 outbreak has brought about various changes in our everyday life. For example, so-called 'social distancing' has resulted in people not gathering densely in one place, leading to sparse offices, auditoria, and other meeting facilities. It has been emphasised that this lifestyle called the 'new normal' should be observed. According to the new normal, it is important to maintain distance between persons, to facilitate enough ventilation, and to wear face masks to avoid droplet infection. Furthermore, to avoid droplet infection, not only a face mask but also a partition is often used, especially in places where people are rather closely situated or cannot wear masks, e.g., eating establishments, shop counters, and meeting rooms.

Particularly in eating establishments, partitions are often used in Japan. In these establishments, to avoid a feeling of confinement, transparent partitions are often employed. Figure 1 shows examples of partitions used in eating establishments, comparing transparent partitions made of transparent acrylic panels and those made of non-transparent plastic panels. Transparent partitions are usually preferred, both to maintain a sense of openness and to allow people to see who they are talking to.

Figure 1. Examples of desktop partitions: (left) one made of non-transparent plastic panels used in a student refectory; (right) one made of transparent acrylic panels used in a meeting room. Both are rather large-sized examples; smaller ones are often used.

In most cases, such partitions are usually made of sound-reflecting material. This causes some acoustical problems, e.g., voices during conversation are reflected by these partitions and can be heard by other people, or strong reflections of one's own voice from the partitions may cause annoyance and disturb speaking [1]. In order to avoid these acoustical problems, it is obviously desirable to attach sound-absorbing materials to the surfaces of the partitions. However, as conventional sound-absorbing materials are non-transparent, this could spoil the most important feature of transparent partitions. Therefore, considering that transparent partitions are preferred, transparent sound-absorbing materials should be employed. In such a case, microperforated panels (MPPs) are the most promising. MPPs can be made out of various materials, as long as submillimetre holes can be made. Therefore, it is not difficult to make an MPP from transparent acrylic (or any resin/plastic) panels.

An MPP was first proposed, along with its basic theory, by Maa [2–4]. Since then, many studies on its development and utilisation have been carried out, and manufacturing methods have also been developed [5, 6], leading to various products (including transparent ones) in recent years [7, 8]. We have also proposed the use of MPP as a spatial sound absorber [9, 10]. MPP is a perforated plate made of any material with a thickness of less than 1 mm and a diameter of less than 1 mm with a hole opening ratio of less than 1%, which are much smaller dimensions than traditionally used conventional perforated panels with larger holes, thicknesses, and perforation ratios. However, the acoustic resistance is optimised by the use of fine holes, and relatively high sound absorption is achieved. As mentioned above, it is not difficult to make transparent panels. We have actually used transparent samples in their experiments (e.g., [9, 10]). Another example can be seen in Kang and Brocklesby [11], where they proposed an acoustic window using a transparent silencer with transparent MPPs.

As a relevant topic, there is another issue caused due to sound insulation by a partition. In the case of desktop partitions, voices are transmitted by diffracting around the partition; however, if the sound insulation of the partition is high, the quality of speech transmission deteriorates, leading to difficulties when talking through the partition. Sugie et al. [12] and Nitta et al. [13] investigated the application of perforated plates to such transparent partitions as a way to ‘improve’ sound transmission, by reducing the sound insulation performance of the partitions. They considered applying perforated panels, which have larger hole sizes and perforation ratios than MPPs, to the partitions to reduce the sound reduction index in the middle- and high-frequency range to facilitate conversation. Since their study focused on reducing the sound reduction index of the partition to facilitate conversation, they did not discuss the sound absorption effect of the installed perforated panels. On the contrary, the authors focused on the sound absorption effect of the attached perforated panels. Both are important viewpoints regarding the improvement of transparent partitions, and they complement each other.

Although both viewpoints are important, this study focuses on the problem of insufficient sound absorption; here, MPPs are proposed to add sound absorption effects to improve the above-described problems caused by insufficient sound absorption. Thus, in this study, a trial production and experimental testing of an acrylic desktop partition with acrylic MPPs were performed. The trial production was designed in consideration for use in not only eating establishments but also offices, meeting rooms, and general-use rooms. In order to prevent the possible penetration of droplets caused by the holes in MPPs, it is important to include a hole-free panel should be included in the partition. This can be acoustically beneficial as the hole-free panel can work as a backing structure for MPPs to obtain a better sound-absorbing effect for sound waves coming from both sides. Therefore, these considerations lead to the design of the partition to make it a triple-layered structure (MPP–unperforated acrylic panel–MPP) and it was adopted for the prototype partition. The prototypes were tested in a reverberation chamber to confirm their sound absorption performance.

## 2. Design considerations and preliminary tests

With regard to the MPP sound-absorbing structure applicable to partitions, the authors previously proposed a double-leaf MPP space sound absorber (DLMPP) [9, 10], which consists of two MPPs arranged in parallel with an air layer in between, whereby the structure as a whole is permeable. As mentioned above, when considering desktop partitions for preventing droplet infection, it is desirable to use an unperforated plate in combination with MPPs to create an impermeable structure as a whole; thus, a triple-leaf structure with two MPPs and an unperforated plate in between is more suitable. This is also appropriate to provide sound absorption on both sides.

In this case, the MPP on each side and the unperforated panel in the middle basically constitute a single MPP sound-absorbing structure, which is a combination of two single MPP sound absorbers. Therefore, the design theory of a single MPP absorber can be employed, which is relatively simple. Furthermore, it is desirable to use a thick transparent plate, because the unperforated plate in the middle needs to have a certain weight. A thinner and lighter plate will not be able to play a sufficient supporting role for the MPP.

In addition, considering its purpose, it is necessary to use a material which can be easily cleaned and disinfected, and which is transparent and durable. Therefore, we selected 2 mm-thick acrylic panels for both the MPP and the unperforated panels.

An overview of the trial partition is shown in Figure 2, which is based on a size commonly used in restaurants. Although this size is rather small for use in an office or meeting room, it is a standard size for a restaurant; if a larger partition is required, this can be accommodated by using multiple partitions. The overall thickness should be as thin as possible in order to save space, but other factors should be taken into consideration; there is a limit to both thinness and thickness because of the requirements in terms of acoustic properties. The sound absorption frequency range needs to be close to the frequency range of the human voice; hence, the thickness of the air layer needs to be adequate. Considering the space-saving aspect of this prototype, we decided that a total thickness of about 36 mm would be appropriate. Given that the panels are 2 mm thick, this resulted in there only being a 15 mm air layer between the MPP and the middle unperforated panel.

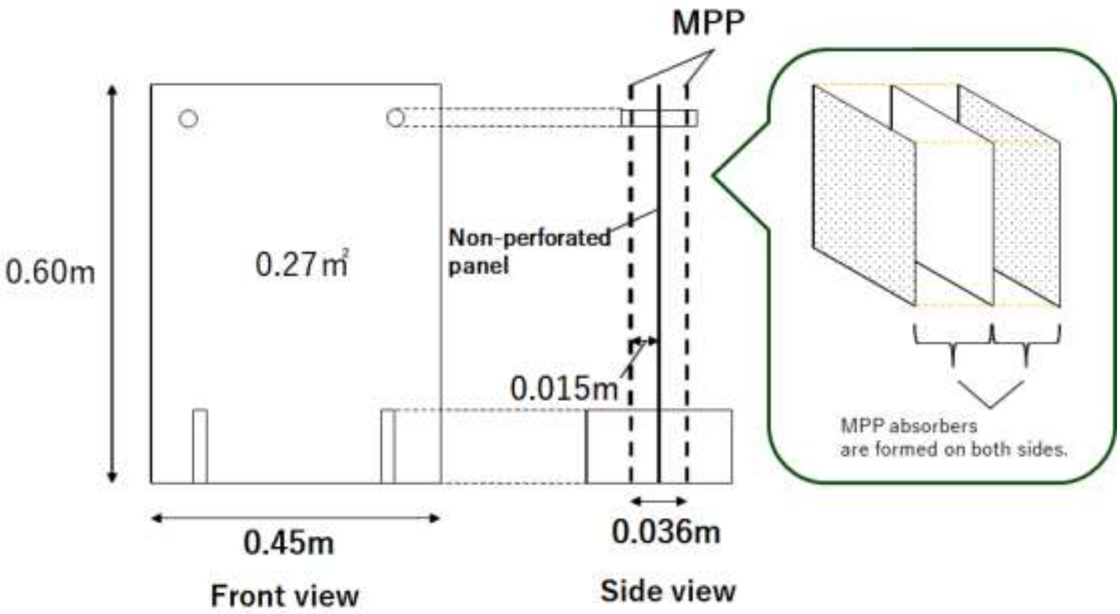


Figure 2. Design sketch of the prototype microperforated panel (MPP) acrylic transparent desktop partition. The area of the prototype in the figure describes one side. The acoustical concept of the overall sound-absorbing structure is summarised in the sketch on the right. The legs supporting the partition are 120 mm x 80 mm and made of 5 mm thick acrylic sheets. When placed on the floor, the three panels are almost in contact with the floor. All parts were made of acryl and no damping material was used.

Under the above conditions, the specifications of the MPP were studied. In general, the design of MPPs is based on the assumption that they are homogeneous as a whole, with all holes having the same diameter and being equally spaced. However, in the present case, due to the thin air layer and the low target sound absorption frequency range, larger holes and a lower perforation ratio were required. Therefore, for this prototype, we decided to use an MPP with a combination of large and small holes. The advantages of this combination considered both visual design and acoustics, as discussed below. In this study, three different 100 mm square samples with different combinations of hole diameters were constructed, and the parameters were determined by trial and error on the basis of preliminary measurements using impedance tubes. Details of the samples measured are shown in Table 1.

Table 1. Parameters of the samples for preliminary tests. Hole separation refers to the distance between a hole and its neighbouring hole regardless of the hole diameter. All samples were 2 mm thick. The back cavity refers to an air cavity, which had a depth of 15 mm in all cases.

<table>
<tr><th>Sample</th><th>Hole diameter 1</th><th>Hole diameter 2</th><th>Hole separation</th><th>Cavity depth</th></tr>
<tr><td>A</td><td>0.7 mm</td><td>0.3 mm</td><td rowspan="3">10 mm</td><td rowspan="3">15 mm</td></tr>
<tr><td>B</td><td>0.7 mm</td><td>0.4 mm</td></tr>
<tr><td>C</td><td>0.8 mm</td><td>0.4 mm</td></tr>
</table>

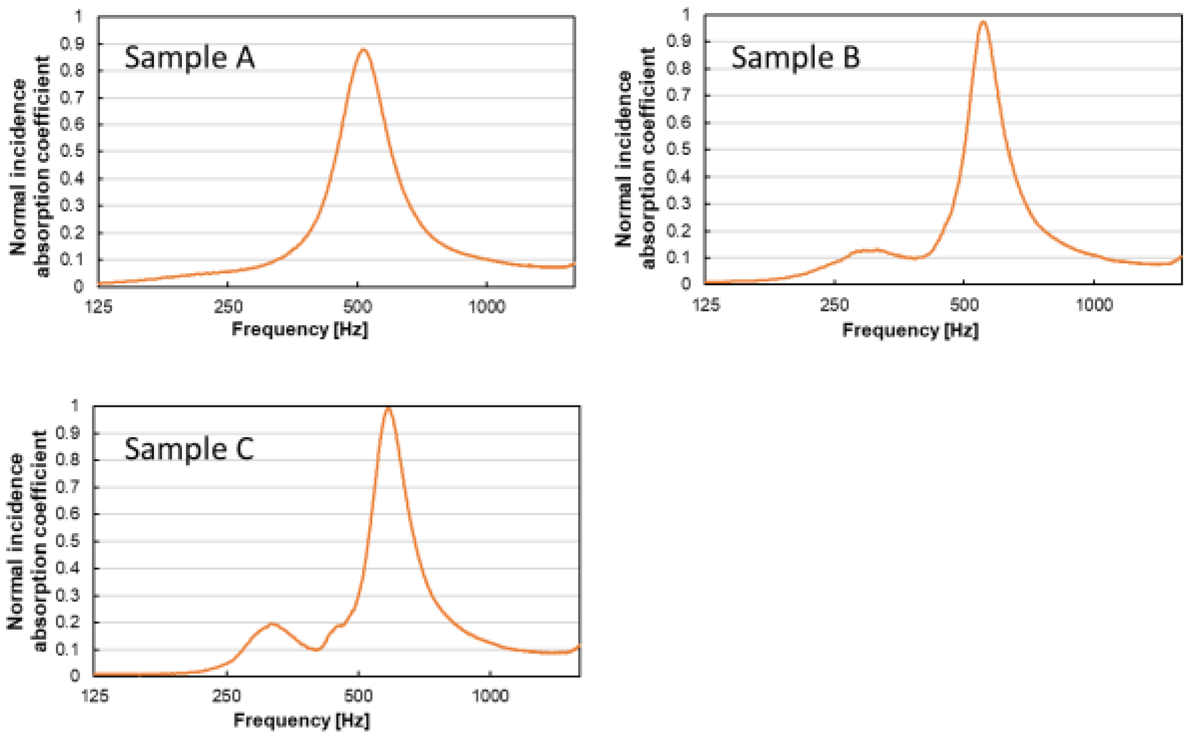


Figure 3. Results of the preliminary tests of Samples A, B, and C using an impedance tube (transfer function method). Tests were performed with a square impedance tube of 100 mm length; therefore, the upper limit of the measurement frequency was 1600 Hz.

The normal-incidence sound absorption coefficients of the three samples (A, B, and C), shown in Table 1, were measured using the transfer function method in an impedance tube, according to ISO10534-2 [14]. The measurement results are shown in Figure 3. Sample A showed the lowest peak frequency among the three, but the peak value was slightly lower than the others; Sample C showed the highest peak at the highest frequency. From these results, it was decided to adopt the parameters of Sample B, which had a relatively low peak frequency, close to that of Sample A, along with a higher peak value than Sample A.

The effect of the combination of large and small holes was that, when viewed from a distance of about 1 m from the sample, the large holes were only slightly visible while the small holes were barely visible. As such, the apparent number of holes was small. From an acoustic point of view, it was necessary to increase the perforation ratio in order to lower the frequency of peak sound absorption; however, this was relatively easy achieved because of the large holes. On the other hand, the small holes also acted beneficially in terms of ensuring necessary acoustic resistance.

Once the specifications were determined, trial prototypes were constructed according to Figure 2, and the reverberation room method was used to investigate their diffuse-field sound absorption characteristics. The details are described in the next section.

## 3. Experiments on prototypes

As mentioned in Section 2, we prepared prototypes for our experiments. In the subsequent experiments using these prototypes, we sequentially examined the experimental results and proceeded with the study by improving them through trial and error which consists of the following three steps, i.e., Steps 1 to 3. In this section, the experimental results and the trial-and-error steps of specification improvement are described together.

### 3.1 Step 1: Original design

First, the measurements of the trial prototype designed as above were made. All trial prototypes were made of a 2 mm thick transparent acrylic sheet, adopting the parameters of sample B in Table 1, i.e., the first specimen was made using exactly the same specification as described in the previous section. Hereafter, this is referred to as Specimen (a). Photographs of Specimen (a) are presented in Figure 4.

Figure 4. Photographs of Specimen (a). Detailed information of its characteristics is given in Figure 2.

The experiments were carried out in an irregularly shaped reverberation room with a volume of 317.4 $m^3$ and a surface area of 282.3 $m^2$, with sound diffusing panels, according to JIS A 1409 (ISO354 [15] compatible). The measurements were carried out using the interrupted noise method, with three sound-receiving points and two sound source positions. Ten prototypes were randomly placed on the floor in the central area (more than 1 m distance from the walls) of the reverberation chamber with at least 1 m distance to each other; this seemed reasonable considering their intended placement on a desk or table in reality. Thus, the prototypes were open on all sides but closed at the bottom in the experiment. One side of a specimen is 0.27 $m^2$, thus it has 0.54 $m^2$ for both sides. Therefore, the total surface area for ten specimens is 5.4 $m^2$.

The results of the measurements are shown in Figure 5. For comparison, the measurement results of the case where the two MPPs were removed and only the middle acrylic unperforated sheet remained are shown in the figure. The measurement results are presented as the total equivalent sound absorption area for all specimens divided by the number of specimens (10 in this case), i.e., the equivalent sound absorption area per specimen. As can be seen from the results, the sound absorption characteristic of the unperforated acrylic panels was almost zero, indicating that almost no sound absorption is expected for a conventional acrylic partition with the unperforated panel alone. On the other hand, Specimen (a) showed some sound absorption above 500 Hz. Therefore, the addition of an MPP to the acrylic partition had a certain effect. However, the sound-absorbing effect was not large, the peak sound absorption characteristic of MPP absorbers was rather indistinct, and the overall performance was less significant than expected.

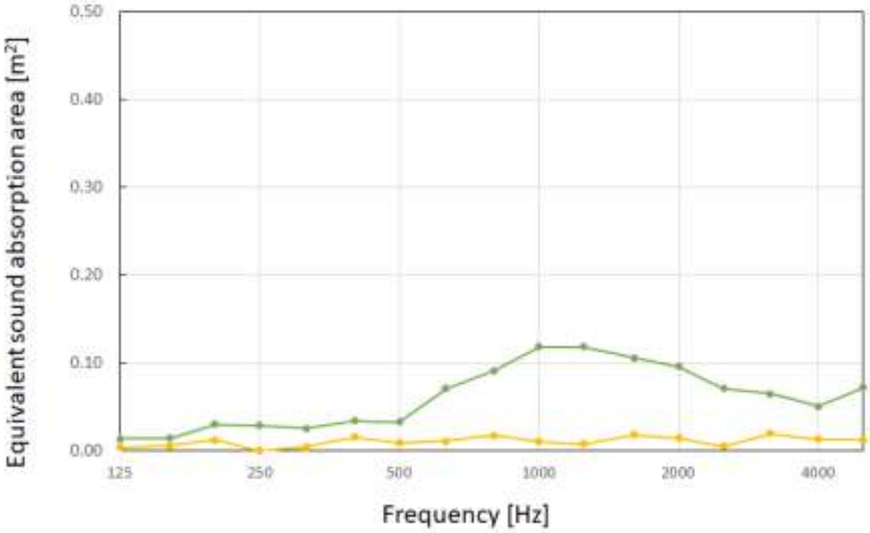


Figure 5. Measurement results of Experiment 1. The green curve shows Specimen (a), in comparison with the unperforated panel only, prepared by removing all MPPs from Specimen (a) (yellow curve). All results are presented as the equivalent sound absorption area per specimen.

As such, the reason for the sound absorptivity of Specimen (a) being lower than expected was interpreted. The three sides being open may have affected the sound absorption performance, e.g., diffused sound could have been incident inside the partition through these openings, and incident sound on MPPs could have also leaked out through the openings. In any case, openings on the periphery seemingly deteriorated the resonance absorption performance of the MPP partitions on a whole. Accordingly, wrapping the periphery to close the openings should somewhat increase the absorptivity.

### 3. 2 Step 2: Effect of wrapping perimeter

In the preceding step, we confirmed that Specimen (a) showed a certain sound absorptivity, however, it is unexpectedly low. This was attributed to be caused by the open periphery through which the sound inside the air layer leaked out, and it was considered that it should be closed. Therefore, the three opened areas (top and sides) of Specimen (a) were wrapped with adhesive tape and closed. This is hereafter referred to as Specimen (b). Figure 6 shows the photographs of Specimen (b), and the measured results are shown in Figure 7 in comparison with Specimen (b) and the unperforated panel.

Figure 6. Photographs of Specimen (b), with the same specifications as Specimen (a) but with its periphery wrapped by adhesive tape.

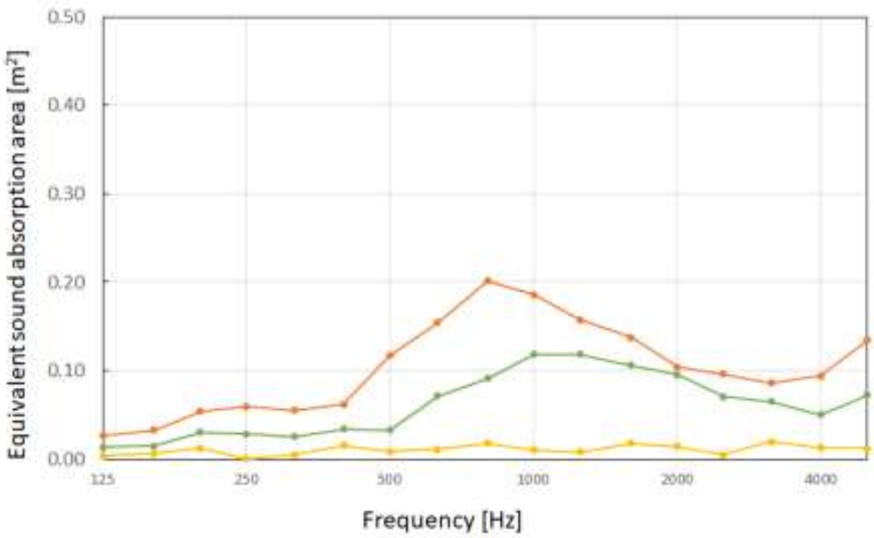


Figure 7. Measurement results of Specimen (b). The orange curve shows the equivalent sound absorption area of Specimen (b), in comparison with that of Specimen (a) (green) and the unperforated panel only (yellow). All results are presented as the equivalent sound absorption area per specimen.

The adhesive tape used was not thick or heavy enough to completely block the sound; therefore, this was a rough and simple solution. Even so, the sound absorption performance was much improved. In view of this, it can be inferred that the MPP does not fully demonstrate its sound absorption effect when all four sides are open.

This result can also be interpreted by considering the size of the partition (0.6 × 0.45 $m^2$), which is smaller than the wavelength below 500 Hz. According to previous work [16, 17] on the effect of honeycombs behind MPPs and permeable membranes, when the air space behind the material is partitioned smaller than the wavelength, it shows a local reactive behaviour. This leads to a confirmed effect of the peak frequency shifting to the lower-frequency range and the sound absorption performance improving. The difference between the experimental results of Specimen (b) and those of Specimen (a) was also due to a shift in peak frequency to the lower-frequency range and an improvement in sound absorption performance, which can be explained by the same phenomenon. On the other hand, the results of the unsealed Specimen (a) showed a shift in peak frequency to a higher frequency than that of the impedance tube result (Figure 2) and a decrease in sound absorption performance, which can be considered as an extended reaction effect of the unsealed back layer.

Therefore, we decided to slightly change the original design; the top and side openings were closed with acrylic panels, which is, hereafter, Specimen (c). As the bottom area was basically enclosed by floor, it was left open. In the next step, we show the results of the prototype experiment using Specimen (c).

### 3.3 Step 3: Prototype with closed perimeter

As discussed in the preceding step, we proceeded into the prepare the improved specimen with closed periphery, Specimen (c). The photographs of Specimen (c), which is basically the same as Specimen (a) but with its top and side areas closed with acrylic sheets of 2 mm thickness, are shown in Figure 8. The sheets used to close the peripheries were not glued but instead fitted together; therefore, the specimen was not perfectly airtight.

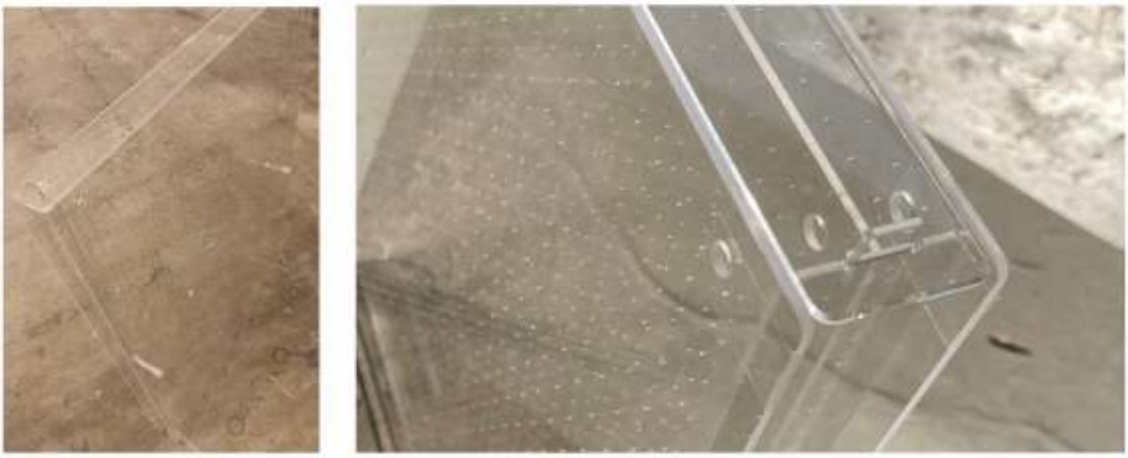

Figure 8. Photographs of Specimen (c). The top and side areas were closed using acrylic sheets (unperforated). These were simply fitted together and not glued. The covering panels on the perimeters were not glued but  fitted in with prongs and notches with other parts.

The equivalent sound absorption area of Specimen (c) was measured using the same procedure as before. The measured results are presented in Figure 9 in comparison with the other specimens.

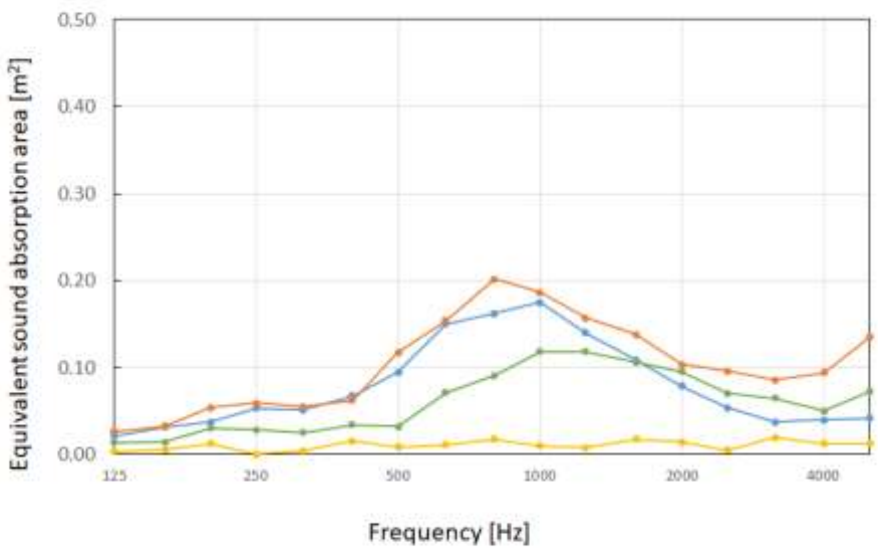


Figure 9. Measurement results of Specimen (c). The blue curve shows the equivalent sound absorption area of Specimen (c), in comparison with that of Specimen (a) (green), Specimen (b) (orange), and the unperforated panel only (yellow). All results are presented as the equivalent sound absorption area per specimen. Numeric data of Specimen (c) are given in Appendix as supplementary data.

Specimen (c) showed an equivalent sound absorption area to Specimen (b) up to 630 Hz, but a slightly lower one at higher frequencies, while the difference increased above 2000 Hz. Therefore, the results were generally comparable to those of Specimen (b), and the effect of blocking the perimeter was apparent. We did not find a clear reason for the higher sound absorption of Specimen (b) in the high-frequency range above 2000 Hz; however, this may have been due to the characteristics of the adhesive tape used. Since Specimen (c) was made using non-absorptive acrylics, the observed difference may have occurred.

However, Specimen (c) showed a higher sound absorption than both the partition with only an unperforated acrylic panel and the MPP partition with an opened periphery (Specimen (a)). Due to the small area of Specimen (c), its equivalent sound-absorbing area was not necessarily higher than that of a conventional sound-absorbing material, but it is expected to be slightly better than that of an unperforated acrylic partition, considering the acoustic conditions of eating establishments, offices, meeting rooms, etc. By using more than one partition depending on the situation, it may be possible to alleviate some of the problems associated with partitions in restaurants, offices, and meeting rooms.

In this study, the effect of the application of MPPs as acrylic desktop partitions was confirmed, although it was somewhat mild. Further improvement will be possible by optimising the parameters of the MPPs used in the partition. For this purpose, a parametric study with perforation ratio, hole diameter, etc, will be needed both in theoretical and experimental method. This will be one of the primary topics of future studies.

## 4. Concluding remarks

In this paper, we proposed an acrylic partition with transparent MPPs as a means of mitigating the problems caused by acoustic reflections due to transparent acrylic partitions, which have often been used in eating establishments, offices, and meeting rooms since the COVID-19 outbreak. The proposed structure consists of three layers: an unperforated acrylic sheet in the middle and MPPs on either side. In this study, we decided to use heterogeneous MPPs with a combination of holes of two different diameters, and we conducted preliminary experiments to determine its parameters. A trial prototype using these parameters was evaluated, which was subsequently improved on the basis of the measurement results in the reverberation room. The results can be summarised as follows:

1. The addition of an MPP allows the acrylic partition to become sound-absorbing. However, the MPP does not provide sufficient sound absorption when the top and sides are open. This is because the resonant sound absorption mechanism does not work sufficiently due to the incidence and leakage of sound waves from the open areas. This is also interpreted by the difference between local and extended reaction behaviour of the sound absorption system.
2. The sound absorption performance is significantly improved when the open areas (top and sides) are closed. However, due to its small size, the equivalent sound absorption area per prototype was moderate, being lower than that of general sound-absorbing materials. (For reference, see Appendix.) However, considering that acrylic alone is mostly reflective, this is considered somewhat useful for improving the sound environment.

In this study, the prototype experiments were conducted using only a few specimens; thus, the above findings are limited. In order to further improve the MPPs, it will be necessary to conduct additional studies, including more prototypes and implementation experiments in real environments. In order to improve the sound absorption performance, the parameters of the MPP need to be investigated. For this purpose, a parametric study both in theory and experiment will be necessary. Particularly, a theoretical model analysis will be helpful for a practical design. In this case, if a heterogeneous MPP is chosen, including visual factors, it will be necessary to predict its appropriate sound absorption characteristics. These issues will be discussed in the future.

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Data availability: The data used in this study are available upon reasonable request.

Author contributions:
K. Sakagami, conceptualisation, supervision, writing—original draft, and writing—review and editing; M. Kusaka, data curation and writing—review and editing; T. Okuzono, data analysis and writing—review and editing; S. Kido, prototype design; D. Yamaguchi, project management.

Appendix
Here, as supplementary datasheet, a Table of exact values of the results for Specimen (c) is shown in Table A1. It is easily observed that a partition with unperforated acrylic panel only does not absorb sound energy. Regarding the final form of the prototype, Specimen (c), considering the surface area per one specimen was 0.54 $m^2$, the peak value per unit area (equivalent to absorption coefficient) is 0.33 at the peak (1000 Hz). A commercially available transparent micro-slotted material, which requires larger air-back cavity though, shows a peak absorption coefficient higher than 0.5 (e,g. [8]). This value may vary due to the conditions, such as cavity depth, etc., therefore, it is not simple to compare. However, Specimen (c) needs to be further improved for comparable sound absorptivity.

Table A1. Equivalent sound absorption area of Specimen (a) in comparison with a partition with unperforated panels only.

| Frequency (Hz) | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unperforated panel only | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.02 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 |
| Specimen (c) | 0.03 | 0.02 | 0.03 | 0.04 | 0.05 | 0.05 | 0.07 | 0.09 | 0.15 | 0.16 | 0.18 | 0.14 | 0.11 | 0.08 | 0.05 | 0.04 | 0.04 | 0.04 |

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