ACOUSTICS IN ARCHITECTURE

BY

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The three principal considerations in the designing of a room or hall and looking toward acoustical perfection, are that of securing the greatest loudness at all points of the hall if a sound produced at some particular point, the proportional loudness of all component sounds or in other words the avoidance of all interference of sound and the greatest possible distinctness of successive sounds. When these three considerations are satisfied the hall will be acoustically perfect, but as these cannot all be satisfied at the same time the result is naturally a compromise.

It is a well-known fact that buildings which are good for speaking are seldom good for music and vice versa. This is particularly true of
Churches. There are a number of churches in which the music of the choir and organ is very fine, but in which the minister can scarcely be understood. This is probably due to the reinforcement of the sound and resonance, so much needed in music but very disastrous to speaking. There are therefore really two classes of buildings according to acoustical use, whether for musical or speaking purposes, however they will not be treated separately, but mention will be made and distinctions drawn at the proper times.

According to the theory of the German writer, Barth, sound is governed by the same laws of dissipation as light, that is that the intensity decreases as the square of the distance from the source of the sound, also that the area affected increases as the square of the distance. These laws together with...
the one governing reflection, that the angle of incidence is equal to the angle of reflection, would apparently give a mode of investigation for the acoustic properties of a hall. These laws however would only affect loudness and interference and nothing could be determined as to the distinctness, this last being affected principally by absorption, or the lack of it and to some extent by interference. There are so many unlooked-for difficulties arising at all times though, that only in the simplest cases do the laws hold. Therefore I have chosen, as a general scheme for investigation, to take up each of the three principal difficulties separately, and observing the effect of plan, section, scaling, proportion, construction and materials, heating and ventilation and anything else which may affect them, upon each. The observations will be from actual examples
and experiments.

The modes of treatment for loudness are numerous. As in the design of halls the plan is the first condition investigated, so it should be here. Here, as in all points on acoustics there is a great diversity of opinion. Existing an effort to group buildings according to their size has been made by some authors. The grouping is based upon the assumption that the ordinary speaker can be heard 90 feet in the direction in which he speaks, 75 feet on each side, 30 feet to the rear and 45 feet vertically. The grouping is then done in this way: first, buildings in which the dimensions fall within the range of the voice and in which the sound reaches the listener by direct radiation; and buildings which exceed the range of the voice in size and in which the sound must be conducted by devices of design, construction and material.
Another grouping has been made by Guillemain in his "Physical Forces." He divides rooms into three classes: first, the concert-room, where the orchestra or speaker is placed or should be placed in the sound focus, and where everything is subordinate to the auditor; the theater, where there are two sound foci, one for the orchestra and one for the actors; and third, the hall for deliberative assemblies.

The groupings are of course for loudness alone and take no account of interference or distinctness.

Now as to shape of plan. It has been urged by some that simplicity of plan is desirable. This is not always true as in the case of square and rectangular rooms, the corners often affect the sound so as to detract from the volume and also to produce confusion. The effect of sound waves striking very obliquely on the wall surface was shown by Scott
Russell to be that of a roller, the sound not being reflected directly, that is the angle of reflection equaling the angle of incidence. It has been found advantageous to round out the corners of the room say in a parabolic form, thus reflecting the rays forward and parallel to each other. If the rectangular form is adopted, Dr. Brewer suggests that the length should be about two-thirds greater than the width in order that the sounds reflected from the side walls may mingle with the voice and strengthen it.

Of circular plans there are numerous bad examples. St. Paul's is one, the London Colosseum and Dublin Rotunda others. The rotunda of the U.S. Capitol at Washington is circular in plan and the space above reaches to nearly the full height of the dome. Here sounds are much confused and a single sharp sound resembles until it dies away in time and space. The domes above
in all three cases are undoubtedly to blame as much as the circular plans. The effect is probably due to reson-ance and echo for the most part. The whispering gallery of St. Paul's is renowned as is also the one in the Capitol at Washington. In the circular concert room of the Fine Arts Society in Berlin, the wall is broken by a large number of deep embrasures; these seem to have the effect of breaking up the echo and reson-ance as little difficulty is experienced here.

I find several instances of octagonal rooms being bad acoustically, although one sixteen sided room covered with hemispherical roof with gallery and windows below is stated as being good. This is Surrey chapel, Black-friars, England, and is quoted by Sanders. Here, as with the embrasures of the Fine Arts Society Hall, the success is probably due to the breaking up of interfering echo and
Resonance by the gallery.

The elliptical form for plan has been tried in Albert Hall, London, but as was predicted was a total failure as the form concentrated the sound at the principal foci only. In the ancient amphitheatres this form was used or rather that of an oval with remarkable success; but this was probably due to the fact that no covering was used and the speaker's voice was conducted directly to the hearers.

The oval or egg-shaped plan was tried in the Mormon Temple, Salt Lake City, Utah, with very marked success. The building is shaped like half an egg and the faintest sounds are distinctly heard across the full length of the immense hall. This form was imitated in an auditorium at Grimsby Park but was a wretched failure, for some reason unknown.
The amphitheatre plan has been tried with varying success. In some cases it has proved to be a distinct success and in others the echoes have been very confusing. In these cases however it is stated that the echoes were due to the speaker being placed in the focus of the curve, and that sounds from the sides were free from the defects.

The rectangular hall with curved ends has been successful to some extent and it has been suggested that the ends made in the form of parabolas and with a parabolic covering over the speaker that a good effect might be obtained. The difficulty here would lie in that all sounds originating in the hall would be concentrated at the focus of the parabola or at the position of the speaker, which would prove to be very annoying. The effect of the semi-paraboloid of revolution would be thought to tend
all the utterances of the speaker directly into the hall
in parallel rays and thus the full volume of sound
and the greatest loudness would be produced.

The horse-shoe plan is the one generally adopted
for theatres and with success as a rule. The lower
floor is scarcely ever out of range of direct radiation
and the galleries can be so arranged as to give the
full advantage of reflection, while they at the same
time help to break up disturbing echoes. The slightly
funnel shape, with the stage at the small end takes
advantage of the discrimination of sound according
to Orth's rule. The galleries are not always a help but
are sometimes together with the boxes a source of much
trouble, this varying with different conditions.

The plans of churches vary greatly. One of the most
common is the one with transepts. In regard to transept,
there is the usual diversity of opinion expressed.
Some claim they are an advantage as the sound cannot be reflected back or rolled along so as to create disturbance as it escapes into the transepts. Others claim that it is a positive disadvantage as the sound is detracted from at its origin. My own experience in the Chapel of the Lehigh University would tend to show that the side arms are bad. Here the words of a speaker in the chancel are echoed and reechoed and remonstrated until when it reaches the back of the church the words are no longer distinguishable, but only a rumble which continues long after the source of sound is stopped. This effect is produced even now after formal remedies have been tried, namely that of hanging heavy curtains from the ceiling, cutting off the upper part of the transepts from the main body of the church, and that of a soundproof or reflecting board of the apparent form...
of the segmental portion of the surface of a sphere, having been hung over the pulpit. The pulpit is placed at some distance to the right of the centre line of the church, against the wall. Any sound from the chancel however is treated in the same disturbing way. The difficulty was finally overcome by erecting another pulpit in the main body of the church as shown on the plan.

This building furnishes a striking example of what I first mentioned, the fact that a building poor for speaking was not necessarily a poor one for music, for in this instance, the music of the organ and choir could not be heard to better advantage. The reason for this is probably the reason for the defects of speaking. The great resonance of the high ceiling and transepts adds much to the beauty of the music.
Having now covered the subject of plans in relation to the loudness of acoustic effect, a few conclusions may be drawn.

It is safe to say that the rectangular or square plans are far from ideal, as with ordinary ceilings the echoes arising being very disturbing. With rounded corners the effect is better. Circular plans are to be avoided, as also elliptical, but if the secret of the Mormon Temple success is discovered, the oval plan might prove to be useful. Upon the whole the horse-shoe plan, used in theatres seems to be the most satisfactory and with proper care and treatment appears to be almost certain of success. As to church plans, it seems that transepts are a distincting feature and should be avoided. The ordinary rectangular plan being preferable, the high ceilings doing away with the echoes and the superfluous sound being lost in space.
In the consideration of sections the question of echo and interference arises. It is said by 
Gauts" that a sharp quick sound can produce an echo when the reflecting 
surface is 55 feet distant, but for articulate sounds at least double this distance is necessary. The opinions 
of experts are at variance as to the form of roofs: one State 
that a flat or nearly flat ceiling is the best form for 
a large music-room. It breaks up the echo and assists 
in destroying it, while a semi-circular vault collects 
and focusses it. Others insist upon some kind of a 
curved form for the ceiling, but the nature of the 
curve is the difficulty. If semi-circular or parabolic 
the danger of focussing arises. Still others urge that it 
should be in the shape of a cooach-roof, this being a 
very flat curve, and probably this is to prevent focussing. 
A curved ceiling or one with sloping sides is certainly 
good as this prevents sharp angles and corners which
are always sources of evil. If the farther walls are so far away as to make an echo which will arrive too late to reinforce the sound for the hearer, they should be deadened by some covering so that they will absorb instead of reflecting. The ceiling should extend low behind the speaker and the sides and rear of the hall. The distant walls will probably be occupied by galleries which would break up the interfering echoes and absorb with the aid of cushions and people the valueless sound. It should be borne in mind also that that sound is not only detracted from by distance, but also by absorption while passing over the garments of the audience. Therefore if the ceiling be very low it is probable that those in front will be able to hear well while those in the rear will hear little. Under a low gallery the hearing is usually bad because the only sound entering comes directly from the source and
What reinforcement the rest of the hall offers is entirely lost to those beneath the gallery. Therefore the seating beneath the gallery should not be deep. On the contrary, those in the gallery above receive the benefit of any reinforcement the hall offers besides having the advantage of receiving sound less detraded from by absorption as it has passed high above the audience on the lower floor. On this account galleries may be made much deeper although the incline of the seats should be great, not only for the purpose of seeing better but on account of receiving the sound less obstructed and having lost less by absorption. This also prevents bare walls in the rear to reflect prejudicial sound to other parts of the hall.

Probably the best acoustic effect can be obtained by the use of the modern form of theater section. In this the walls deviate from the stage and the hall reach.
to its greatest width at the rear. The same is true of the ceiling, it sloping upward and to the rear. In this form the full volume of sound is carried out to the auditor and the dissemination of sound according to Ort's rule is taken advantage of. An advantageous arrangement of seats as well of boxes and galleries can also be had.

Plate I is a longitudinal cross-section of the German Opera House in the Schiller building, Chicago; the reflection of sound from the stage is there shown. The stepped arrangement directly above the stage would reflect the sound to the seats of the first floor, but this reflection would arrive too late to be advantageous and therefore the steps are crowned with ornament which break up and tend to kill the reflection. The higher plane surface reflects the sound to the front seats of the gallery and the top and rear portion of the ceiling reflects the sound to the
back seats. The lower portion of the gallery reinforces the sound in the back seats of the balcony. The circular portion under the gallery does nothing toward reinforcement but reflects the sound down behind the seats where at least it is not detrimental. The front balcony and the lower seats are evidently designed to receive the sound directly. The funnel shaped theatre is well exemplified in this case, for the auditorium enlarges rapidly from the stage outward. The front elevation or rather a lateral section is given on plate II. The circular section of the steps and upper portion would make the reflection cross and recross to such an extent that little can be shown by plate except for the gallery where the reflecting surface is flat and horizontal except at the ends where the corners are cut off.
SECTION OF GERMAN OPERA HOUSE.

SHOWING LINES OF REFLECTION OF SOUND.
In all work where acoustics success is desired, the relative proportion of plan to height is of importance. So it may be said that the ceiling should be low but still in the proper relative proportion. What this proportion is, is a question. One writer, Dr. Brewer by name, recommends that the length should be about two-thirds greater than the breadth and the height somewhat greater than the breadth. Others urge the use of the "harmonic proportion." Mr. W. Fletcher Barrett describes it thus: "It appears that for good acoustical properties a building should be so constructed that its different dimensions shall be in some simple relationship to each other. An analogous effect is well known in music, for if two notes have the simplest possible relationship to each other's rate of vibration as 1 to 2 or an octave, the combination of those two notes is more harmonious than any other combination. Next to this would be the ratio
of 2 to 3 or the fifth and next the ratio of 3 to 4 or
the interval of a fourth, the harmony decreasing with
the simplicity of the combination. Further, in the case
of three numbers a musical or harmonic proportion
exists, when the first is to the third as the difference
of the first and second is to the difference of the second
and third. Thus, 2, 3, 6 are in harmonic proportions
because $2: 6:: 1: 3$. Some buildings erected with the
proportions 2: 3: 5 have been successful and the
Boston Music Hall one of the best American exam-
pies of acoustically successful buildings is in har-
monic proportion. His Majesty's Theatre, England,
is house, shoe in form and not in harmonic
proportion 67 x 56 x 57 and is very poor. A German,
Baron von Hausen, found by experience that good
results were obtained where the hall is twice
the breadth in height or 2: 3: 4. Mr. A. I. Oakley
lays great stress on his correction of a town hall in Massachusetts where he reduced the proportion to 3:4:5 by the introduction of book-cases. An acoustic success was the result of the change. This is one example of a test under precisely the same conditions, in and out of the harmonic proportion is enough to slamp the theory as correct, but there is difficulty in applying it to irregularly shaped rooms.

The materials and construction are of the utmost importance in an effort to get the greatest loudness. There is the difference of opinion as usual as to the best materials, some saying that they should be inelastic while others say elastic. It appears that this depends entirely upon the volume of air allowed to each person or in other words the size of the hall in comparison to the seating capacity. Mr. Oakley says that from exhaustive experiments it has been deter...
mind that when the number of cubic feet of space exceeds 195 per person it becomes necessary to adopt a resonant material for ceilings or walls. That when the space exceeds 210 cubic feet per person, the walls and ceilings should both be resonant and as the space exceeds this, the walls should be thinner and of more porous wood. An air space must be left back of this wood. For low cubic capacity, the walls should be hard and repellent. The hard smooth walls act as better reflectors and where there is no necessity for resonance they are undoubtedly best. The value of wood for reinforcing by its vibrations is well known. Wood of a uniform fibre especially fir is recommended to augment sound. One kind only should be used in order to secure uniformity. In construction, floorings should be hollow, placed over a hollow. Lining detached from
The walls with air spaces are excellent for vibration and boxes covered with thin plants, hollow columns and so forth are advantageous. Platforms should be hollow as sound originating on a solid base is more feasible than when on a resonant base.

There are adverse opinions to the above, some stating that floors should be of concrete adding fireproof construction to the claimed acoustic properties. Plaster on canvas is recommended, standing away from the walls and leaving an air space as with the wood, but this construction does not give the reflecting surface which the wood affords.

It seems as though the materials and construction would depend mainly upon the use to which the hall is to be put. For musical purposes nothing could be better than thin resonant walls and ceiling they would add both volume and force and without
doubt wonderfully improve it. For speaking only solid, well placed, good reflecting walls would be preferable as distinctness and not volume is the desired quality. For a combination of speaking and music a compromise would have to be made as solid walls would give too great sharpness to the music and too much resonance would disagreeably affect the speaker. A resonant platform for both is needed however, as a person speaks with difficulty on a solid base.

In the design of heating and ventilating plants, the care greater is needed as the transmission of sound is greatly affected by the condition of the atmosphere through which it passes. The velocity and intensity are dependent on the density and impurity of the air. The denser the air the greater its conducting power and the effect of humidity is marked. Temperature
also augments the rate of transmission to the extent of almost 2 feet for every degree centigrade advance. By experiment it has been shown that unless the air is in a perfectly homogenous state the transmission of sound is interfered with. In audience rooms the air is far from being in a homogenous state. This is due to the gases exhaled by the people and the heating and lighting outlets. This difficulty gives rise to what are called "Acoustic clouds," which are clouds of sound moving in currents due to the currents of air from heating and lighting. It has been suggested that it would be a good scheme to produce a slight current of air passing over the stage to the audience to convey the sound. This would be produced by means of ventilation. It would be of undoubted advantage to direct the currents of air in the direction in which it is wished that the sound should be
conveyed. It is also important to retain the equality of the air. Many experiments have shown that variations in temperature are very prejudicial to good hearing. In experiments on the Baltimore Academy of Music, important data was established. The whole supply of air comes from the back of the stage, is there warmed, passes over the stage horizontally, through the proscenium arch, and thence somewhat diagonally toward the roof, across the auditorium, in one grand volume and with gentle currents so as almost entirely to avoid the formation of minor air currents. It is exhausted by an opening in the roof, and by registers in the ceilings of the galleries. In going out it passes over the central chandelier which will its heat assists in the ventilation. The amount of air is about 1500 cubic feet per minute. This affords ample heat and ventilation and keeps
a nearly uniform and constant temperature, throughout the house. It is claimed that the acoustic properties are excellent and are not due to the plan or materials but to the condition of the air. By a series of experiments of shutting off the ventilation and with a number of observers in different parts of the house, it was shown that no perceptible difference was made when the ventilation was in action and when not. Mr. J. Roger Smith claims that sound travels better across the wind than with it, and if this is true a central ventilating flue in the ceiling is certainly an advantage as then the sound would travel at right angles to the ascending air; however, it must be understood that the direction of ventilation is hardly comparable to the wind, the main object of ventilation being to keep the air free from "acoustic clouds" and in as nearly perfect
Condition for the transmission of sound as possible.
A plan suggested by Thomas Boyd, A.R.I.B.A., to have the
same effect as the moist atmosphere before a
storm, in which sound can be heard long distances,
by the prevention of the dispersion, is to introduce
moist air at the top and allow it to settle within
10 or 12 feet of the floor and then take it out at
the sides. This would only be applicable to buildings
with high domes or ceilings.

Further than the plans suggested I cannot go, but
it is very evident however that the greatest care in
designing the heating and ventilation systems is
necessary in order to secure the proper uniformity
of temperature and condition throughout the hall.

There is a minor consideration which may be men-
tioned here, that of the keynote of a room. It is well under-
stood that every hall or room has a keynote, that is
Here is a certain note to which the volume of the room corresponds and in consequence responds with greater activity. Therefore if the speaker will accommodate his voice to this pitch, he is much better heard. Music played in the Key-note sounds much better than when played in other Keys. The materials, proportions and fitting together with the volume are the determinants of the Key-note. This note has been determined for numerous music halls and it is asserted that unless the Key-note is adhered to the effect is very bad.

The subject of devices which are not necessarily permanent fixtures, but which are intended to increase the loudness of sound will next be treated. There are several of these which have been tried with varying success.

The ancients, advised by Vitruvius, used what are called "acoustic vases," to what advantage is not known.
The vases were of different sizes and somewhat on the order of the Helmholtz resonator. When the note was struck corresponding to the vase it without doubt augmented the sound by the sympathetic vibration of the air within. The vases were placed under the seats of the audience, with the opening toward the stage. The sympathetic vibration of a piano or other stringed instrument is well known, and this fact has been utilized in the stringing of tuned wires in the auditorium to augment musical sounds. A variation of this has been tried with slight success. In this case plates of sheet metal of different sizes and thicknesses and consequently of different musical pitches were hung around and near the source of sound and the sympathetic vibrations of these with their respective notes were struck were supposed to increase the volume and force of the sound.
The stringing of tight wires was tried for another purpose in a small parish hall with reported success. The hall was covered with an ordinary gable roof rather high. The sounds in the hall were much disturbed in different ways presumably by the resonance and echo of this open space above. The idea was conceived to string wires across the hall about 12 feet above the floor and accordingly it was done. The wires were placed from 1½ to 3" apart and tightly stretched. A great improvement was the reported result. This was due to the wires taking up the valueless sound and transmitting it directly to the walls and roof. The wires had the advantage of catching the direct sound and also the reflected waves. It is doubtful whether there is really any practical advantage to be gained from such a treatment, as the wires would be disagreeable to look at and it is certain that all the wires could
not respond to all sounds and therefore the efficiency
would be low.

The next phase of the subject to be treated is the
interference of sound waves. Up to this point it has
been assumed that the direct and reflected waves
of sound reinforce each other, but this is not always
the case, on the contrary they sometimes act in opposi-
tion. From the theory of sound it is known that the
sound travels in waves of condensation and rare-
faction. These two waves, opposite in character, taken
together constitute a single sound wave. Now if
the wave of condensation going by the direct path
arrives at the same time as the wave of similar
character from the reflected ray, then the sound
is reinforced, but if the wave of condensation
meets the wave of rarefaction they neutralize each
other and comparative silence will result. The
cause of this would be the difference in the lengths of the paths as the sound waves are of equal length. The greater the number of reflecting surfaces the more complex becomes the interference, and as each tone has its own wave length and in consequence a different point of neutralization the problem is exceedingly difficult to solve. In fact, no general method of investigation would be possible with so many conditions imposed. A room is covered with regions of varying intensity due to this influence. In an experiment on a room known as the constant temperature room in the Physical Laboratory at Harvard University, the regions of loud and feeble sound have been mapped out. The room is plain, there being no windows and the floor flush with the wall. An experiment carried on there illustrates the point. The sound wave a
middle C organ blown with steady pressure. The observer on changing the position of his head by 10 or 12 inches, could hear the note change in the most positive manner from middle C to an octave above. The explanation is that the organ did not give a simple tone, but a fundamental middle C with several overtones. Each tone had its own system of interference waves. The region of silence for one system happened to coincide with the region of reinforcement for the other and vice-versa, and by moving the head 10 or 12 inches the different tones were heard.

The character of plan together with the section would probably have much to do with the results of interference. It is evident that the paths of reflected rays should, if possible be so arranged in lengths that they are multiples of the wave length. This would bring the direct sound and reflected sound together correctly at certain points, thus...
An arrangement could be made for one tone, but with a multiplicity of tones it is impossible as the wave lengths vary. Therefore a good result in this respect is simply a matter of chance. No arrangement of seating could be made to avoid the regions of failure as they vary with the different tones. Economy of seating space would also present anything irregular.

It is possible that by the artificial movement of air by heating and ventilation that the difficulty might be overcome to some extent. By the method before explained or a variation of it, the wave lengths of the sounds might be so altered as to give a satisfactory result. This could only be determined by experiment and it is likely that benefit to only a few notes would result.
The difficulty of superfluous sound and its remedy, absorption, is not so intricate as the last and much easier of investigation. The theory is simple. Sound being energy, once produced, will continue to exist as sound until transmitted or transformed into some other kind of energy, usually heat. This process of transformation is called absorption. Often in halls the sound is produced and the residual sound continues so long after bounding from wall to wall, that the original sound is not distinguishable at the far end at all. This would be the case with continuous sound only, such as speaking. This may arise from two causes depending on the size of the audience. The audience is of course the chief absorbing material and the defect may arise from too small an audience to properly transform the sound. If the audience is a large one and the defect still continues, the fault is in the design of the building,
and is due to the auditorium not properly directing the residual sound so as to take advantage of the audience.

A number of interesting experiments were carried on in the Physics Lecture Room of Harvard University and from these a quantitative determination was made. The relative absorbing powers of various substances was tested. The duration of the residual sound when the room was empty was determined and a small amount of standard substance was brought in. The duration of the sound was again taken. By successive tests a curve was plotted which shows the effect in seconds of any number of square yards of hair cushion. Other tests with different substances, curtains, canvas, hair felting and people were made and a table of relative absorbing powers compiled. Tests of girders
and scattering showed them to have almost no absorbing power at all. Plate shows the table of direction of residual sound in seconds for each 100 yards of cushion. The reduction for the first few yards is seen to be great but from 200 yards on, little difference is made. Plate is a table of the relative absorbing powers of different substances. Audience is evidently the most economical and one of the most effective of the absorbers. Hair cushion are very effective and the most easily provided of any.

In designing a hall to prevent residual sound it is suggested to so incline the walls and ceilings as to throw the sound directly on the audience, which, as shown by the table, is one of the most active absorbing agents. The seats should be provided with cushions in case the audience is small.
TABLE SHOWING DIRECTION OF RESIDUAL SOUND.
### Relative Absorbing Powers

<table>
<thead>
<tr>
<th>Material</th>
<th>Absorbing Power per sq. yd.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hair Cushions on seats</td>
<td>2.03</td>
</tr>
<tr>
<td>Heavy Oriental Rugs on floor</td>
<td>56</td>
</tr>
<tr>
<td>Chenille draped as curtain</td>
<td>1.32</td>
</tr>
<tr>
<td>Cretonne Cloth hanging flat</td>
<td>33</td>
</tr>
<tr>
<td>Hairfelt against wall ½ thick</td>
<td>1.00</td>
</tr>
<tr>
<td>&quot; &quot; &quot; 1&quot; &quot; &quot; &quot;</td>
<td>1.80</td>
</tr>
<tr>
<td>&quot; &quot; &quot; 2&quot; &quot; &quot; &quot;</td>
<td>2.40</td>
</tr>
<tr>
<td>Audience per person</td>
<td>1.3</td>
</tr>
<tr>
<td>Individual man sitting clear</td>
<td>1.8</td>
</tr>
<tr>
<td>&quot; Woman &quot; &quot;</td>
<td>2.2</td>
</tr>
<tr>
<td>Canvas Cloth hanging flat</td>
<td>0.71</td>
</tr>
</tbody>
</table>
A room tested by experts and with a piano showed the residual sound to last 2.5 seconds and was pronounced satisfactory. This length of duration probably helped the music, but it is doubtful if it would have been satisfactory for speaking purposes. The effect of hair felting against the wall is good but would be expensive in construction and far from fireproof.

Plan, section, ventilation, heating, etc. have little effect on absorption, except in directing the sound so as to take the greatest possible advantage of the absorbing agents. Construction and materials especially the latter are the determining factors of absorption.