USE OF CORK SHEETS FOR ROOM ACOUSTIC CORRECTION

Gino Iannace,[1]* Giuseppe Ciaburro,[2] Luigi Guerriero[3] and Amelia Trematerra[4]

ABSTRACT

Cork is a sustainable material and at the end of its useful life it can be disposed of into the environment without causing damage. This paper analyzes an acoustic correction system made of cork sheets mounted at an opportune distance from the walls inside a room. The cork sheets have a thickness equal to 1.5 mm. The sound absorption coefficients of the cork sheets were initially evaluated by mounting samples inside an impedance tube, then creating a back cavity at a suitable distance from a rigid wall. The distances considered were: 3, 5, 10 and 15 cm. A room used as an office with a volume of about 90 m^3 and plastered walls was considered as a case-study. In this type of environment, suitable acoustic comfort conditions are required. The acoustic characteristics were analyzed through a virtual model with an architectural acoustics software in an empty room and then with the introduction of sound-absorbing cork sheets. Measurements of the acoustic characteristics of the empty room were taken and subsequently with the walls lined with cork panels mounted at a distance of 3.0 cm from the rigid rear wall. A configuration was analyzed, in line with what was carried out in the numerical model, covering a surface of 5m^2 of the room. The results of the numerical simulations as well as the experimental measurements are discussed.

KEYWORDS

cork, absorption coefficient, acoustic, reverberation time, measurements, acoustic simulation.

1. INTRODUCTION

Cork is obtained from oak bark, with the tissue being composed of spherical granules containing air, making the panels light and elastic. It is an organic coating tissue of secondary origin, which covers the stem and roots of woody plants, that, with its compact structure, is waterproof and fire resistant. It is biodegradable, recyclable, renewable, widely available and has relatively low manufacturing costs. Cork also has the advantage that at the end of its useful life it can be disposed of without any difficulties and without damaging the environment. Research in the field of applied acoustics and energy saving is currently focusing on the application of organic material so that chemical industry products can be replaced by materials of plant origin. The absorption coefficients of hemp, kenaf, gorse and sheep wool have been studied [1–6]. Cork

1-4. Department of Architecture and Industrial Design, Università della Campania "Luigi Vanvitelli," Borgo San Lorenzo 81031, Aversa (Ce)—Italy (*corresponding author, gino.iannace@unicampania.it)

can be a good thermal insulator insulation material used for the construction of building components and is a "sustainable material." However, only the absorption coefficient values of semi-rigid cork panels of an appropriate thickness and different grain sizes are reported in current literature. The presence of a binder to obtain the semi-rigid panels reduces the sound absorption values [7]. The sound absorption values are relatively low due to the grain size and the binder used reduces the passing of air and therefore reduces the sound absorption. This paper discusses the application of cork sheets with a thickness equal to 1.5 mm as an acoustic absorbing material [8]. When a thin flexible panel is placed at a distance from a rigid wall, it absorbs a part of the incident sound energy. The sound absorption is highly influenced by the distance of the panel from the rigid rear wall. This means that a greater depth of the cavity moves the absorption towards the low frequencies [9]. The use of thin cork panels, mounted at a distance appropriate from a rear rigid wall, can be used for the acoustic correction of rooms. In this work, a room used as an office in which adequate conditions of acoustic comfort are necessary has been considered. The walls of the room are in smooth plaster and when people speak in this environment an unwanted sound tail is generated. The mono aural acoustic parameters were measured (T_{30}, EDT, D_{50}, C_{50} and STI) which correspond to conditions that are not excellent for understanding speech [10].

Subsequently, the acoustic characteristics of the room were analyzed with an architectural acoustics software, with a virtual model being created in which the acoustic characteristics of the plaster walls were replaced by the acoustic characteristics of the sound absorbing cork surfaces. This simulation made it possible to evaluate the effectiveness of the use of thin cork panels. In order to verify the results of the numerical modelling as well as the effectiveness of the use of thin cork panels, the acoustic characteristics of the room were measured with the walls covered by1.5 mm thick cork panels mounted at a distance of 3.0 cm from the rear rigid wall. A configuration was analyzed in line with what was carried out in the numerical model, covering 5m^2 of the room with cork sheets. The results of the numerical simulations and the experimental measurements are discussed.

2. ABSORPTION COEFFICIENT MEASUREMENTS WITH THE IMPEDANCE TUBE

The sound absorption coefficient at normal incidence was measured according to the procedure described in ISO 10534-2 [11]. This method allows measurement of the acoustic parameters by using small samples mounted inside an impedance tube. The tube has the following dimensions: internal diameter of 10 cm (corresponding to a lower limit of 100 Hz, an upper frequency limit of 2.0 kHz), and a length of 56 cm. The distance from the two measurement microphones was 5 cm [12]. The sound absorption coefficient measurements were taken for cork panels with a thickness of 1.5 mm. To better analyze the effectiveness of the sound absorption of the cork sheet, the sample was mounted with a back cavity of 3, 5, 10 and 15 cm. Figure 1 shows a schematic drawing of the measurement setup performed with the impedance tube creating a back cavity behind the thin cork panel. Figure 2 shows the absorption coefficient values for the samples mounted at different distances from the back cavity [13]. The acoustic measurements show that upon increasing the cavity behind the cork sample the maximum sound absorption value moved towards the low frequency range. The cork panels with a thickness of 1.5 mm have good absorption coefficients at medium frequencies. These panels act as extended absorbers, but with a reduced thickness of the cavity behind the wall, the value of the absorption coefficient

TABLE 1. Values of the acoustic absorption coefficient in 1/3 of the octave bands.

Frequency, Hz	125	250	500	1.0 k	2.0 k	4.0 k
Absorption coefficient	0.13	0.20	0.45	0.80	0.56	0.45

moves towards high frequencies. For the cavity with a thickness of 15 cm, the maximum absorption was around the frequency of 300 Hz, for the thickness of 10 cm, the maximum absorption was around the frequency of 400 Hz. For the cavity with a thickness of 5 cm, the maximum absorption was around the frequency of 600 Hz. For the cavity of 3 cm, the maximum acoustic absorption was obtained at a frequency of 900 Hz. For all the cavities considered, the value of the absorption coefficient was reduced as it went down towards the low frequency areas. The material behaves like an extended absorber around the maximum absorption frequency, and the absorption coefficient around the frequency, in which it has the maximum absorption, has the form of a very enlarged bell. The thin cork panels can be considered as a valid alternative to traditional sound absorbing materials. The high absorption obtained in some frequency bands, depending on the back cavity depth, confirmed the possibility of using cork panels for the acoustic correction for different types of rooms. The 3 cm cavity is the best suited for the acoustic correction of closed environments, since it provides an absorption coefficient value greater than 0.8 in the frequency range between 700 Hz and 1.2 kHz. Table 1 presents the values of the absorption coefficient measured of the cork sheets measured in 1/3 of the octave bands for this configuration; the values of the absorption coefficient at 4.0 kHz are obtained as an extrapolation of the values measured.

3. ACOUSTIC MEASUREMENTS

The office studied has smooth plaster walls with a wooden door and glass windows, the plan is 5.0 m long and 5.0 m wide, the height is 3.5 m and the volume is about 90 m^3. Figure 3 shows the office in which acoustic measurements were carried out. In order to analyze the acoustic characteristics of the office, acoustic measurements were taken using an impulsive sound source located in one position. Seven measurements were taken using an impulsive sound source consisting of a rubber toy—balloons properly inflated. The use of the toy balloons as sound source and the analysis of the impulse responses have been previously tested with good results [14]. Using a customized sustaining frame, the height of the sound source was maintained fixed at 1.6 m from the floor. A BRAHMA microphone was used to record the impulse responses

FIGURE 1. Scheme of the impedance tube with a back cavity.

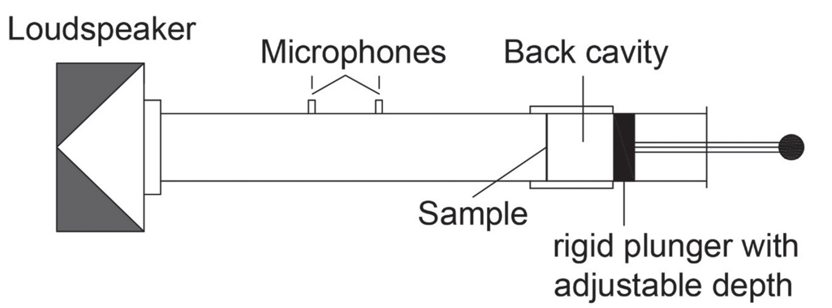
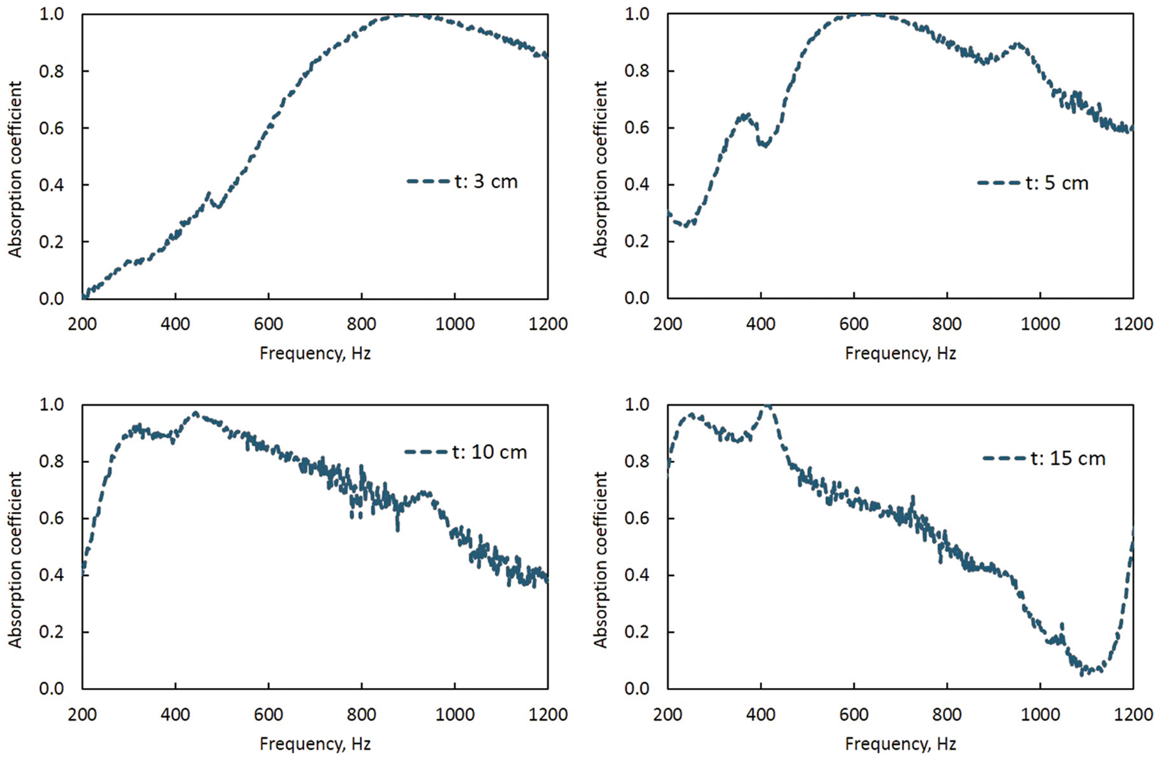


FIGURE 2. Cork sheet thickness 1.5 mm, absorption coefficient values for samples mounted at different distances from the back cavity (t = 3 cm, 5 cm, 10 cm, 15 cm).



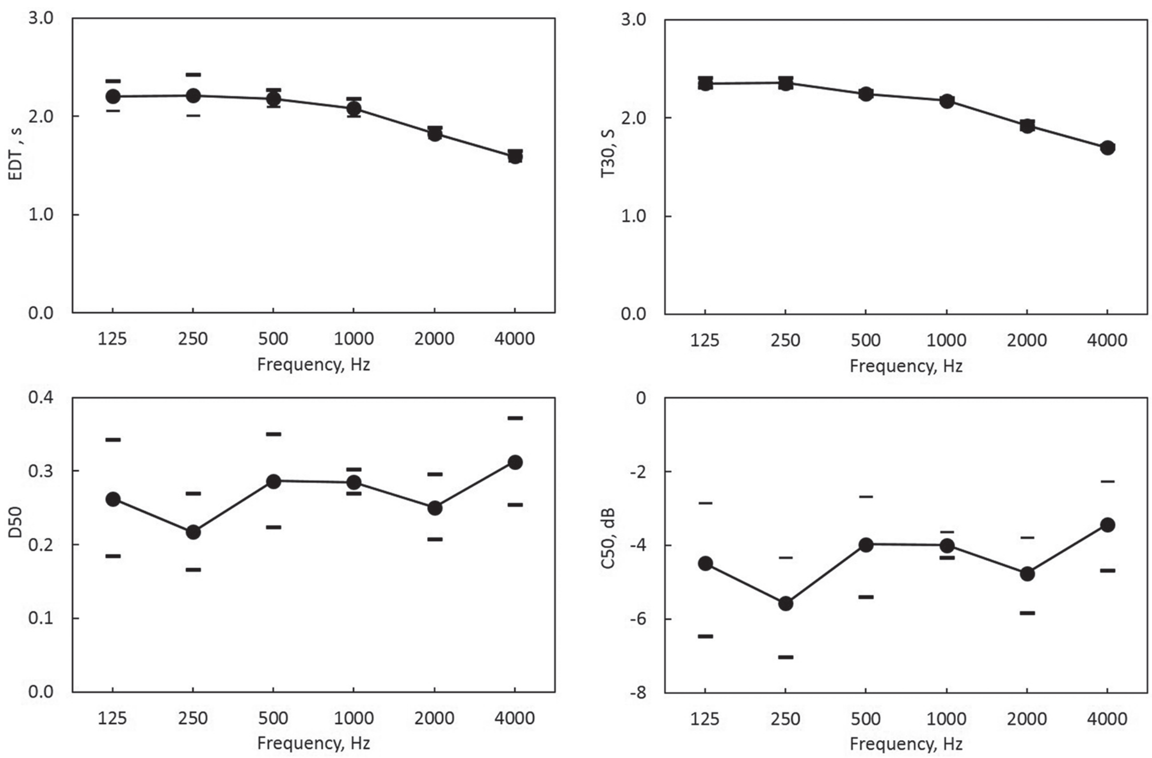
in seven different receivers located in the room at a height of 1.6 m. The BRAHMA microphone is a digital four channels equipment which allowed conversion of the recording into an Ambisonics B-format. The recorded impulse responses were then elaborated with the software Dirac 4.0, and the several acoustic parameters defined in the ISO 3382-1 [15], such as the early decay time (EDT), the reverberation time (T_{30}), the clarity (C_{50}), the definition (D_{50}), and the sound transmission index for speech intelligibility (STI) were analyzed. During the acoustic measurements, the background noise was lower than 35 dBA, the room was empty, the furniture were hard chairs and a hard table. Figure 4 shows the average values and the relative standard deviations of the measured acoustic parameters. The standard deviations of T_{30} and EDT are negligible; therefore, these parameters do not change from point to point, whereas for C_{50} and D_{50}, the significant variation of the values of the standard deviation is a consequence of the fact that these parameters change at every measurement point considered. At the frequency of 1.0 kHz, the value of T_{30} is higher than 2.1 s, D_{50} does not exceed the value 0.3, C_{50} is equal to –5 dB, while STI is equal to 0.46. The acoustic parameters measured give the idea that in this room there is not a good speech intelligibility. Moreover, the tests carried out have confirmed that the speech intelligibility was poor.

4. VIRTUAL MODEL

"Odeon," a software for architectural acoustic, was used for the evaluation of the room surface area to be covered with the absorbent material in order to obtain a good acoustic correction

FIGURE 3. Office in which acoustic measurements were carried out.

FIGURE 4. Values of the acoustic parameters and of the relative standard deviation.



[16–19]. The Odeon software imports a virtual model drawn by a 3D cad. Figure 5 shows the 3D virtual room model with the position of the virtual sound source and the positions of the seven virtual receivers. The software Odeon uses the principles of geometrical acoustics and adopts a hybrid calculation method that combines two classical methods, image source and ray-tracing method [20, 21]. The Odeon program uses a hybrid calculation method, where early reflections are calculated by combining the image-source and a ray tracing method. The transition order (T.O.) at which the calculation method changes from image-source to ray tracing can be adjusted according to the complexity and shape of the room. If T.O. is set to 0 the calculation method used for all reflections will be the ray tracing method. The first post-processing step consisted of comparing the acoustic measurements in the current state with the results obtained from the virtual model. This allowed adjustment of the virtual model until simulated results were obtained as close as possible to those measured. The process consisted of minimizing the differences between the calculated and measured values of T_{30} by tuning the absorption coefficients of the room surfaces. The acoustic model calibration is the first step and it is made by setting the absorbent coefficient values for all virtual model surfaces, so the Odeon's model requires knowledge of the acoustic properties of the surfaces which made up the room. The acoustic model calibration consists of setting the absorbent coefficient values for all virtual model surfaces. The calibration operation is stopped when at each octave band frequencies (125 Hz–4.0 kHz) the value of the reverberation time (T_{30}) calculated is equal to the reverberation time (T_{30}) measured. The goal was to reduce the difference between the simulated and measured values of T_{30} below 5% [22, 23]. After the calibration, the acoustic absorption panels (5 m^2) with the values of absorption coefficient obtained by the "Kundt's tube" were inserted into the virtual model. The values of the sound absorption coefficients of the cork sheets used in the virtual model are shown in Table 1. Therefore, the numerical simulations were carried out covering a surface of 5 m^2. Figure 6 shows the theoretical values of the acoustic parameters obtained from the numerical simulations by the Odeon software. At the frequency of 1.0 kHz, the T_{30} is equal to 1.4 s, while D_{50} is equal to 0.4 and C_{50} is equal to –2 dB. The introduction

FIGURE 5. 3D virtual room model with the position of the virtual sound source, and the positions of the virtual receivers.

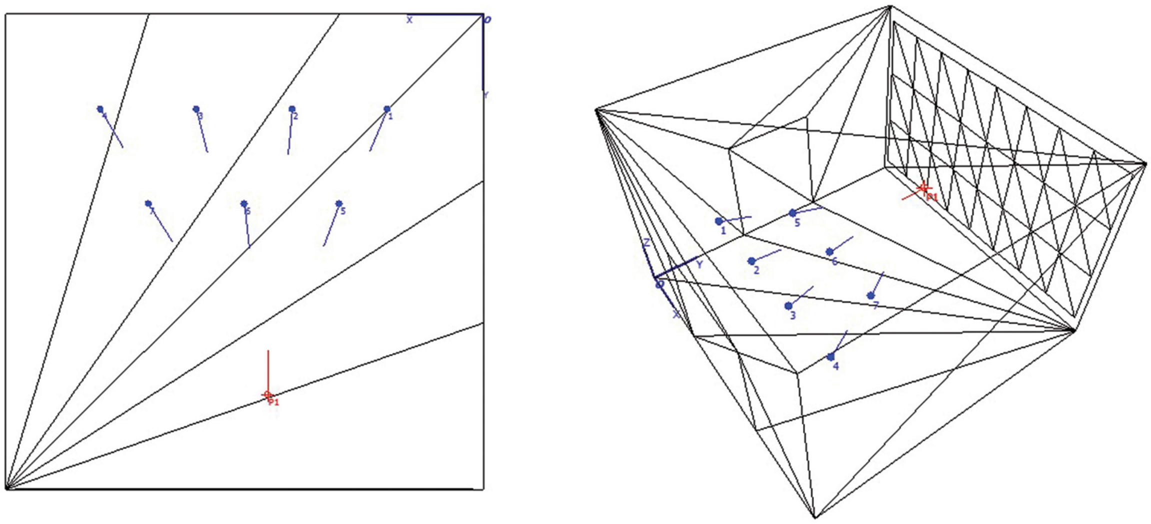
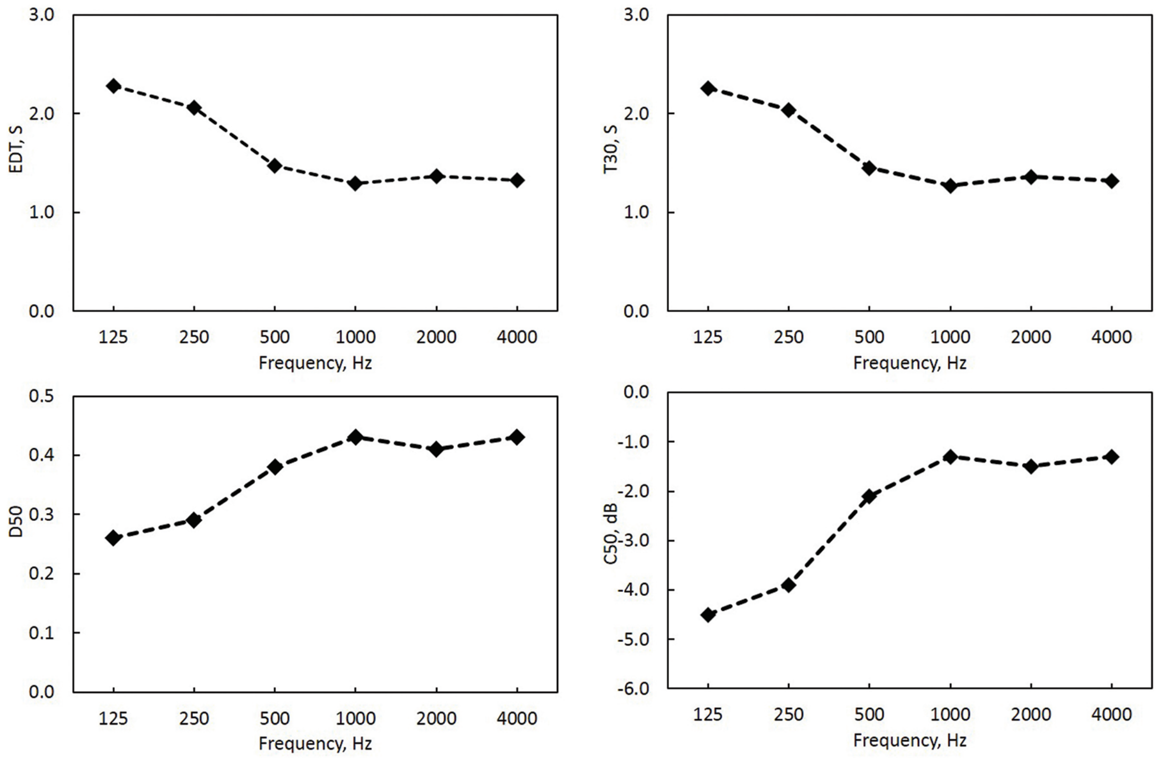


FIGURE 6. Theoretical values of the acoustic parameters obtained from the numerical simulations by the Odeon software.



of cork panels leads to an improvement in the acoustic characteristics of the room. Due to the low value of the absorption coefficient at 125 Hz at low frequencies there are no improvements, but this condition is typical even when traditional sound-absorbing materials are used.

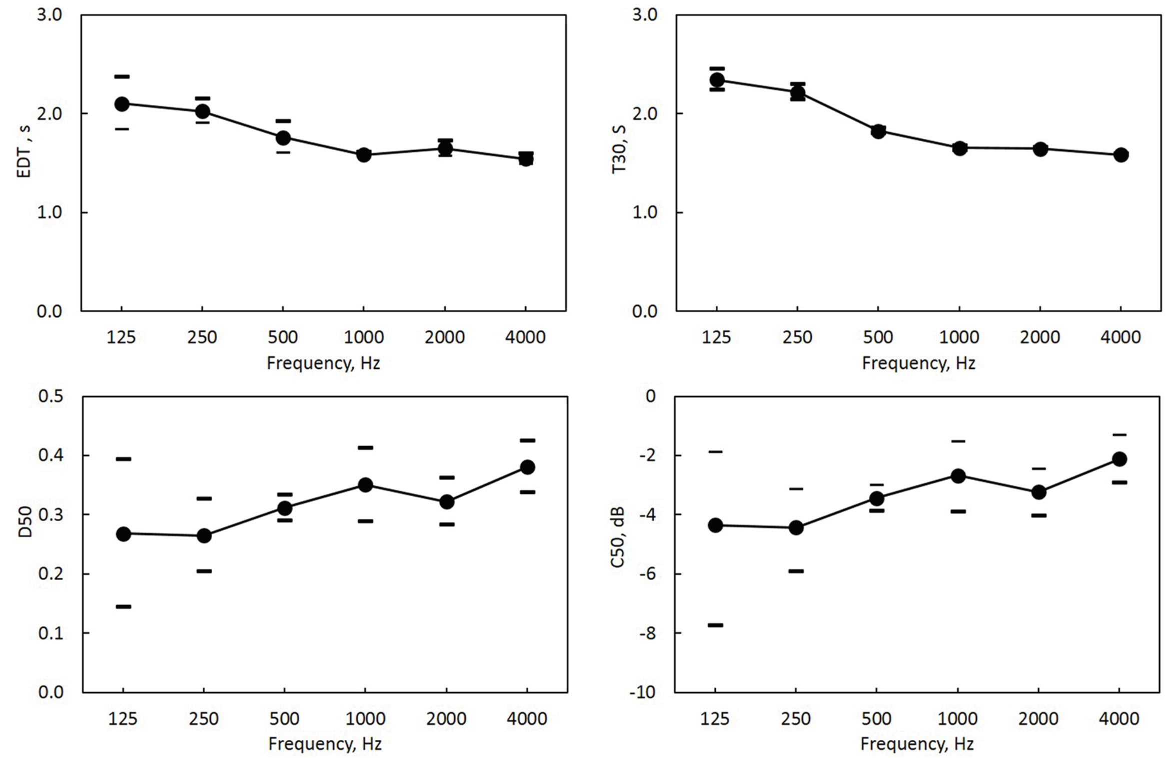
5. ACOUSTIC MEASUREMENTS IN REAL CONDITIONS

Following the virtual model measurements, the cork sheets as absorption panels were put up in the room to cover an area of 5 m^2 in order to evaluate the effects when the surfaces of the walls were covered. Figure 7 shows the arrangement of the panels in the room positioned behind the desk. The cork sheets were placed at a distance of 3.0 cm from the wall with a 3 cm thick wooden rod. Figure 8 shows the details of the elements used to realize the sound-absorbing structure: hammer, tacks, hooks, wooden rod, and cork panels. The impulse response recordings were taken at the seven measurement points in analogy to the empty room as well as the virtual model room. Figure 9 shows the measured values of the acoustic parameters, with the standard deviation, when there are 5m^2 of cork panels in the office. T_{30} and EDT are reduced and as expected D_{50} and C_{50} increased. The standard deviations of T_{30} and EDT are negligible; hence, these parameters do not change from point to point. Whereas for C_{50} and D_{50}, the significant variation of the values of the standard deviation, at low frequency (especially at 125 Hz), is a consequence of the fact that these parameters change at every measurement point considered. The values of the acoustic parameters are in good agreement with the Odeon software.

FIGURE 7. Panels in the office positioned behind the desk.

FIGURE 8. Details of the elements used to realize the sound-absorbing structure: hammer, tacks, hooks, wooden rod, and cork panels.

FIGURE 9. Measured values with standard deviation of the acoustic parameters when there are 5m^2 of cork panels in the office.



6. DISCUSSION

The acoustic measurements inside the room used as an office with rigid walls show excessive values of T_{30} and EDT and low speech intelligibility. Cork sheets were used for the acoustic correction, the thickness of the sheets was equal to 1.5 mm. The value of the absorption coefficient on a rigid wall was measured with the impedance tube; the thickness of the cavity of 3.0 cm is the optimal value of the broadband absorption coefficient in the frequency range between 500 Hz and 2.0 kHz. The software Odeon, for the architectural acoustics, was used to evaluate the effects of the insertion in the room of 5 m^2 of cork panels, the processing of the results allows an estimation for good acoustic correction. Subsequently, 5 m^2 of cork panels (thickness of the sheets equal to 1.5 mm) were installed in the room, mounted at a distance of 3.0 cm from the rigid rear wall. The results of the measurements confirm a reduction of T_{30} and EDT and the increase of D_{50}, C_{50} and STI.

At the frequency of 1.0 kHz, there is a reduction of T_{30} and EDT of about 0.6 s. The values of STI increases, so STI = 0.51. The values of definition D_{50} increases at the frequency of 1.0 kHz, D_{50} = 0.45 (before the acoustic correction D_{50} = 0.3). The insertion of cork panels can be a valid alternative to the use of traditional polyester panels and are environmentally friendly. Panels are easy to install and are very cheap. The use of cork in construction and in the field of acoustic correction could increase the use of this material and allow the development of an eco-compatible supply chain.

7. CONCLUSIONS

This paper shows how it is possible to obtain an acoustic correction inside an office using panels of cork. Cork panels of 1.5 mm thickness were used and showed a good value of the measured sound absorption coefficient. The cork panels are inexpensive; their cost is much lower than traditional sound-absorbing panels and are simple to assemble. The wide availability of cork reduces the production and realization cost of the panels, and more importantly, the material used is completely recyclable. It is also worth noting how the Odeon software provides a good prediction of the room acoustic correction. The model calibration with Odeon software produces acceptable results for the acoustic parameters. The trends of the acoustic parameters measured in the office are consistent with the trends of the absorption coefficient values measured in the impedance tube.

REFERENCES

1. Arenas J.P., Crocker M. J., Recent trends in porous sound absorbing materials for noise control. Sound and Vibration, 44(7), 12–17 (2010).
2. Asdrubali F., Schiavoni S., Horoshenkov K.V., A review of sustainable materials for acoustic applications. Building Acoustics, 19(4), 283–312, (2012). doi: 10.1260/1351-010X.19.4.283
3. Asdrubali F., D'Alessandro F., Schiavoni S., A review of unconventional sustainable building insulation materials. Sustainable Materials and Technologies, 4, 1–17, (2017). DOI: 10.1016/j.susmat.2015.05.002
4. Iannace G., The acoustic characterization of green materials. Building Acoustics, 24(2), 101–113, 2017. DOI: 10.1177/1351010X17704624
5. Yang, W.D., Li, Y., Sound absorption performance of natural fibers and their composites. Science China Technological Sciences, 55 (8), 2278–2283, 2012. DOI: 10.1007/s11431-012-4943-1
6. Ramis, J., Alba, J., del Rey, R., Escuder, E., Sanchís, V.J., New absorbent material acoustic based on kenaf's fibre. Materiales de Construccion, 60 (299), 133–143, 2010. DOI: 10.3989/mc.2010.50809
7. Berardi U., Iannace G., Acoustic characterization of natural fibers for sound absorption applications. Building and Environment, 94(2), 840–852, (2015). DOI: 10.1016/j.buildenv.2015.05.029
8. Trematerra A., Lombardi I., D'Alesio, A., Use of cork as absorbent material. AIP Conference Proceedings, 1859, Article number 020003, International Conference on Functional Materials, Characterization, Solid State Physics, Power, Thermal and Combustion Energy 2017, FCSPTC 2017, India, 2017; Code 129216. DOI: 10.1063/1.4990156
9. Berardi U., Iannace G., Di Gabriele M., Characterization of sheep wool panels for room acoustic applications. Proceedings of Meetings on Acoustics, 28(1), 2016. Article number 015001. Code 125755. DOI: 10.1121/2.0000336
10. Iannace G., Trematerra A., Trematerra P., Acoustic correction using green material in classrooms located in historical buildings. Acoustics Australia, 41(3), 213–218, 2013.
11. ISO 10534-2: 1998. Acoustics—Determination of sound absorption coefficient and impedance in impedance tubes Transfer-function method.
12. Iannace G., Acoustic properties of nanofibers, Noise & Vibration Worldwide, 45 (10), 29–33, 2014. DOI: 10.1260/0957-4565.45.10.29
13. Trematerra A., Lombardi I., Acoustic Properties of Cork Sheets. Key Engineering Materials, 744, 66–70, 2017. DOI: 10.4028/www.scientific.net/KEM.744.66
14. Iannace G., Trematerra A., The acoustics of the caves. Applied Acoustics, 86, 42–46, 2014. DOI: 10.1016/j.apacoust.2014.05.004TechnicalNote
15. ISO 3382: 2009. Acoustics—Measurement of the reverberation time of rooms with reference to other acoustical parameters
16. Vorländer M., Computer simulations in room acoustics: Concepts and uncertainties. J. Acoust. Soc. Am. 133 (3), 1203–1213, 2013.
17. Dalenbäck B. I., Svensson U. P., A prediction software interface for room acoustic optimization. Proc. of the 19th International Congress on Acoustics ICA 2007, Madrid. 2007.

18. Krokstad A., Strøm S., Sørsdal S., Calculating the Acoustical Room Response by the Use of a Ray Tracing Technique, Journal of Sound and Vibration, 8 (1), 118–125, 1968.
19. Bork I., A comparison of Room Simulation Software—The 2nd Round Robin on Room Acoustical Computer Simulation, Acta Acustica, 86, 943–956, 2000.
20. Christensen C. L., Koutsouris G., Rindel J. H., The ISO 3382 parameters: Can we simulate them? Can we measure them?, Proceedings of the International Symposium on Room Acoustics—June 9–11 Toronto, Canada, 2013.
21. Christensen, C. L., ODEON, Room Acoustics Software version 11 manual. URL: www.odeon.dk
22. Trematerra A., Lombardi I., Iannace G., Air dome acoustics. Canadian Acoustics—Acoustique Canadienne, 45(2), 17–24, 2017.
23. Iannace G., Trematerra A., The acoustics of the longobard church of Santa Sofia in Benevento—17th Conference on Applied Mathematics, APLIMAT 2018. Volume 2018-February, 2018, 479–486. Code 135345