Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 3 (2015) 6206 – 6213

Procedia MANUFACTURING

6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015

Intellibility assessment in a square shaped preschool classroom according to the grouping of children of 3 to 5 year of age

Laura Marin-Restrepo[a,b,] *, Catalina Morales-Maya[a,b], Gabriela Guerrero-Teran[a], Ader García-Cardona[a,b], Julie Waldron-Toro[a,b]

[a]*Grupo EMAT, Architecture Faculty, Universidad Nacional de Colombia, Medellín, Colombia*
[b]*PVG Arquitectos, cra 68 49A-29. Of 302, Medellín, Colombia*

Abstract

Architecture and Acoustic are intimately related, been sound an extremely important part of the human natural environment. Sounds give specific qualities to spaces establishing whether or not a hearing condition is pleasant or annoying to those who inhabit them, and may or may not favor oral communication, a fundamental activity in human interaction. A pleasant sound may improve human wellbeing, while a noise can be a great obstacle to a person's comfort, creating discomfort, concentration issues and health problems. The role of architecture is clear, since the form and materiality of a space, change its acoustic conditions. The use of space and the activity to be developed, as such, determine the acoustic requirements. Within these, clarity of message delivered is critical in an indoor environment and it's evaluated through a parameter called intelligibility. The overall object of this paper is to determine whether or not the intelligibility of a space is modify by the way it is occupied. For the case study, an environment with high demands on intelligibility was selected: a preschool classroom with children age 3 to 5 years old, where acoustic requirements are determined by two factors. The first is the very condition of an educational environment, whose primary function is the learning process, for which communication is essential and regarding the field of acoustics concerns, the clarity of the message transmitted orally. The second factor is related to a group of users who have physical characteristics and spatial requirements that must be met from an architectural design point of view. An additional aspect to consider is that the use of space differs from a traditional classroom dynamics, since children that age, appropriate and modify their spatial occupation in several ways. The evaluated space was a square shaped classroom made of a brick based building system, which is a proper representation of the building systems used in traditional preschool educational spaces in the city of Medellín, where the study was conducted. The methodology that was used in this study, focused on evaluating the intelligibility of the space, by both, theoretical calculations and field tests, with measurements and analysis processes that were adjusted to the physical conditions of

* Corresponding author. Tel.: +57 4 4449483.
E-mail address: lauramarin@pvgarquitectos.com

Peer-review under responsibility of AHFE Conference
doi:10.1016/j.promfg.2015.07.939

children, such as the equipment heights and the representation of the phenomenon, besides considering three groupings identified as the most common in kindergartens classrooms: roundtable, backs against the wall and distributed in small groups. The results indicated that the quality of intelligibility in the preschool classroom, in fact, varies according to the type of use for each way of grouping. It was also concluded, that the evaluated types of grouping in the preschool classroom, create different areas with varying intelligibility, allowing to identify were it is necessary to make reinforcements on surface finishes within the classrooms, and to identify places that are optimal location for teachers.

Peer-review under responsibility of AHFE Conference

*Keywords:*children, acoustics, intelligibilty, grouping, human wellbeing

1. Introduction

Human language is a sum of many aspects, being its final purpose, communication. Although not the only way, speech is one of the most important and effective forms of communication, within the forms of expression men use, and is fundamental to the development of many activities. Being based on sound, in order to establish communication, oral expression requires a source, a means by which sound, in this case the message, travels, and a receiver. This process can be influenced and modified by many physical aspects, Rodríguez Manzo[1], for example, highlights that sound behavior is greatly influenced by the characteristics of the space in which it takes place.

Acoustics, the science of sound, which addresses sound production, propagation, detection and perception[2], is the discipline responsible for its study. According to the stated by Rodríguez Manzo [1], for Architecture, being the one that defines space characteristics, the study of acoustic is a vital component, as it allows understanding this phenomena and designing it[1], and by this means, it allows to ensure that the human beings, occupying the space, are comfortable with their acoustical environment.

Each space has specific acoustical needs according to the activities that are develop within it, which need to be met, to ensure acoustical comfort for its inhabitants. Classrooms, for example, have high requirements on this subject, as it is essential for the understanding of the message, for a precise communication and to ensure a proper learning process for the students. Regarding these special needs of each environment, standards and documents where developed to aid architects, engineers and designers to project the spaces according to their acoustical needs.

There are several measurement criteria to determine the behavior and quality of sound in a certain space, as are reverberation, which is a sound phenomenon consisting of a light sound permanence once the original source has stopped issuing it, generate by the wave reflection on the surfaces surrounding the source, and intelligibility, “the possibility of clearly understanding each word broadcast by a spoken source” [3]. Both parameter have specific evaluation methods, responding to different characteristics of sound behavior. Reverberation, for example, is measured as the time it takes the sound energy to decay after the source has stop emitting the sound [1], while, Intelligibility, can be measured as a Percentage Articulation Loss of Consonants (%ALCons), theoretical parameter, based on the Reverberation time Results, that indicates the loss of information due to an incorrect perception of the consonants [4], or in a field test, by a method called the Speech interference level, SIL, which evaluates the verbal intelligibility in cases of direct communication taking place in loud environments, considering a simple measurement of the sound pressure at certain frequencies, the vocal effort of the speaker and the distance between the speaker and the audience[5].

According to the NTC 4595[6], the Colombian standard which contains the design parameters for Educational environments, the Reverberation Time (RT) should be a value between 0.9 a 1 s, and the levels of sound intensity must not exceed 45 dB. Intelligibility, on the other hand, is not mention at any point, and there is no mention as well, of any acoustical differences between classrooms used by adults, and those used by children, the latter having clear differences in their hearing system, when compared with the hearing system of a full grown person, due to their physical development process [7]. They also have a very different classroom dynamic, from those observed in a usual class.

Therefore, this study's purpose was to evaluate a kindergarten classroom for children between 3 and 5 years of age, in order to determine whether or not the acoustical conditions of that particular space are modified by the educational dynamics which occur within, specifically, the way children grouped when performing different kind of activities. The selected parameter to evaluate the acoustical quality of the space, was the intelligibility level, which was measured both theoretically and on the field, by the %ALCons and the SIL methods.

2. Methodology

In order to achieve that purpose, a quantitative and qualitative study was carried out, in a classroom that belongs to one of the kindergartens subscribed to the Medellin's City Hall Early Childhood Program, "BuenComienzo", which was also part of the study[8].

The selected classroom, illustrated on Figure 1(a), belongs to a kindergarten called "Lunita Clara", that eventhough was built before the NTC 4595was issued, contains representative characteristics of most classrooms in the studied city, such as: geometry, volume, materials (cement floor tile, brick walls and concrete slab deck), number of children per group and school day schedule.

According to the stipulated by the City Hall Early Childhood Program, 25 children must occupy a classroom. As a correction factor, the field test was done with 22 children, so that the presence of a researcher and equipment in the classroom was made equivalent to the absorption of the 3 absent children and thus there would not be a significant modification in the absorption that would have the total sum of children.

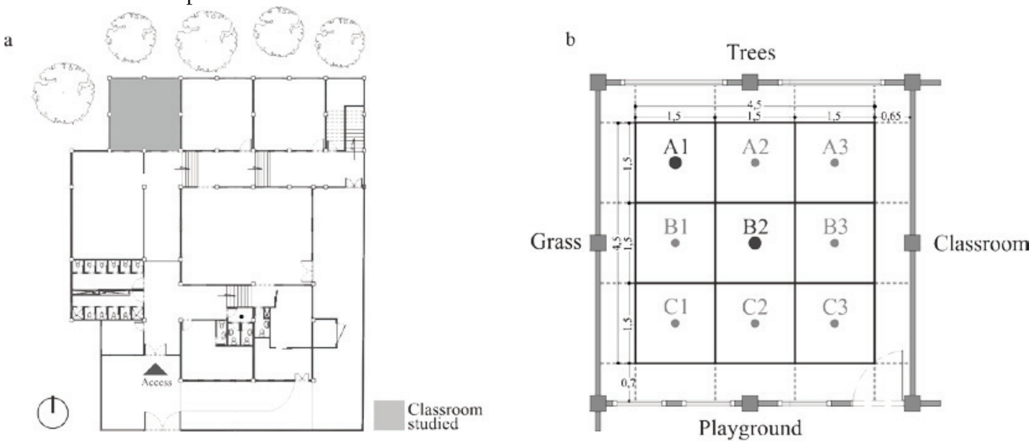

Fig. 1. (a) Location and context of the classroom within the "Lunita Clara" preschool;(b) Grid´s location and code

For its development, the studywas divided into 3 stages. Stage no. 1 consisted in the previous preparation of the evaluated space. The second one was the theoretical evaluation, the diagnosis of the acoustic condition of the room, and the third one, was the field test.

During Stage no. 1, the space plant was divided in 9 quadrants. Each of those quadrants, was a 1.5m side square. This dimension is equivalent to the ideal reception range of the microphone, and the measurement of the diameter of the circumference defined by a group of 5 children, according to observations made in previous occasions. The grid of 9 quadrants was centered in the room, as Figure 1(b) shows. The measurement point was the geometric center point of each quadrant.

For stage no.2, the Reverberation Time is calculated for low, medium and high frequencies, using the equation developed by the Physicist Wallace Clement Sabine, better known as the Sabine Equation (Equation 1). This equation considers the room volume (V), the surface area (S) and the total absorption produced by their materials and the number of people present (based on the absorption coefficient, α), to calculate this parameter.

$$T = 0{,}161\, V / \sum (S * \alpha) \quad (1)$$

Once the reverberation time was calculated, the Percentage Articulation Loss of Consonants (%ALCons), was calculated as well. This parameter when calculated, offers 3 values. The first value is a distance in meters, that by drawing a circle taking this value as radio and the source as a center, defines the boundary between the direct and the reflected fields. The second and third values are percentages, which defined the Articulation Loss of Consonants in each field. Based on these percentages, the fields were qualified according to a rating scale, which goes from Excellent to Bad, as can be seen in Table 1.

Table 1. Relation between %ALCons and the Subjective Valuation of Intelligibility degree

%ALCons	SubjectiveValuation
1.4% - 0%	Excellent
4.8% - 1.6%	Good
11.4% - 5.3%	Acceptable
24.2% - 12%	Poor
46.5% - 27%	Bad

Once stages 1 and 2 were concluded, the field test was initiated. This test is based on a series of recordings within the room, which are taken in order to capture the base sound or noise pollution in which the classroom daily activities take place. To evaluate the intelligibility of the room, and how this parameter was been affected by the surroundings and sound environment, and how clear were the teachers instructions heard in each quadrant, 3 forms of grouping, as shown in Figure 2, were evaluated.

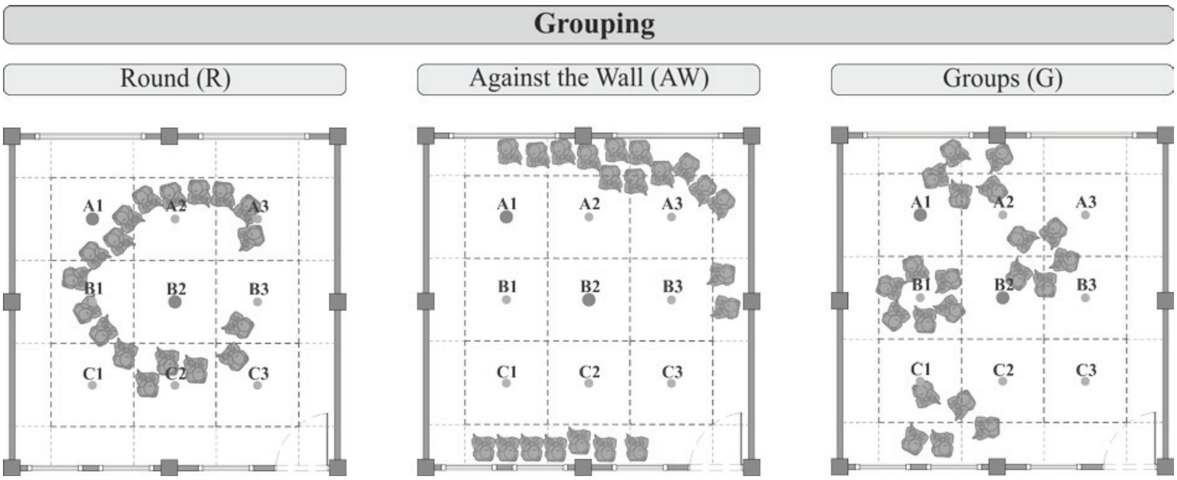

Figure 2. Forms of grouping

In order to simplify the data analysis, a system basedon codes was adopted. The grouping “round table” was identified by an R, siting with backs “against the Wall”, by AW, and “Groups” with a G. Those codes were complemented by adding the emission point to them, obtaining 6 ID codes: RCorner (Round, Corner), RCentre (Round, Centre), AWCorner (Against the Wall, Corner), AWCentre (Against the Wall, Centre), GCorner (Groups, Corner) y GCentre (Groups, Centre).

The evaluation process was carried out according to the following procedure. A monitor emitted a signal from quadrant A1 first and later from B2 in every one of the 3 grouping forms. A microphone was located at the height of the ears of a child standing (approximately 0.8 m) in each quadrant, and the other one was located facing the monitor to annul possible electronic interferences. Electroacoustics Toolbox 2.0.3 Software recorded the sound captured by the microphones, which contained the frequency and time values needed to calculate the “practical” reverberation time and the Equivalent Sound Pressure Level (Leq).

The Speech interference level –SIL, parameter that indicates the Sound Pressure Level that interferes with verbal communication, was calculated based to the Equivalent Sound Pressure Level, according to the equation 2.

$$L_{SIL} = L_{N,A,S} - 8\ bD(A)(2)$$

Where L_{SIL} is the Sound Pressure Level that interferes with verbal communication, $L_{N,A,S}$ is the equivalent sound pressure level measured at the listening position, weighted in dB(A), being A and adjustment made by measurement equipment to better represents the human hearing.

The resulting SIL data was interpreted by granting each quadrant a qualification, according to the rating system shown on table 2. Seeking to graphically represent those phenomena, a color code was given to the rating scale. This color code was then applied each quadrant in an image of the floor plan, looking for a more graphical representation of results.

Table 2. ISO 9921-1 Qualification of the Speech Intelligibility based on SIL

Signal-to-noise ratio at listener's position (dBA - SIL)	**SpeechIntelligibility rating**
< -6	Insufficient
-6 a -3	Unsatisfactory
-3 a 0	Sufficient
0 a 6	Satisfactory
6 a 12	Good
12 a 18	VeryGood
>18	Excellent

3. Results

3.1. Theoretical Evaluation

Table 3. Reverberation Time in Classroom Lunita Clara, with 22 children

Reverberation Time (RT) | Classroom Lunita Clara								
Materials	**Area**	125 Hz	500 Hz	2000 Hz	**Volume**	Total 125	Total 500	Total 2000
Brickwalls	56,68	0,03	0,03	0,05		1,70	1,70	2,83
Cement tile Floor	34,06	0,01	0,01	0,02		0,34	0,34	0,68
Concrete Slab	34,06	0,01	0,01	0,02		0,34	0,34	0,68
Glass	10,24	0,18	0,04	0,02	**98,77**	1,84	0,41	0,20
Metal Doors	2,10	0,49	0,53	0,92		1,03	1,11	1,93
Children	22	0,17	0,26	0,33		3,74	5,72	7,26
Air	4,00	0,00	0,00	0,01		0,00	0,00	0,02
Total	159,14	0,13	0,13	0,20		8,99	9,63	13,62
Reverberation Time						**1,77**	**1,65**	**1,17**
AverageReverberation Time							**1,53**	

3,16Dc	**2,93**	Direct Field radius
%ALCons r<3,16Dc	23,00	Direct Field
%ALCons r>3,16Dc	14,87	Reverberant Field

Table 3, shows the Reverberation Time (RT), calculated using the formula of Sabine, considering the physical characteristics of the space and the materiality of the classroom, also listed on the Table. According to the results, the classroom has a theoretical RT of 1.53 s, which exceeds the upper limit of the standard in 0.53 seconds. Table 3, also shows the 3 values given by the %ALCons calculation. The Direct Field radius for the evaluated space is equal to 2.93 m, the obtained percentages to qualify the Direct and Reverberant Fields were 23.00% and 14.87%, respectively. According to Table 1, both fields were valued as “Poor”. However, Figure 5 shows that in both cases, when the spoken source was located in the center and in the corner, the direct waves covered the larger portion of the classroom area.

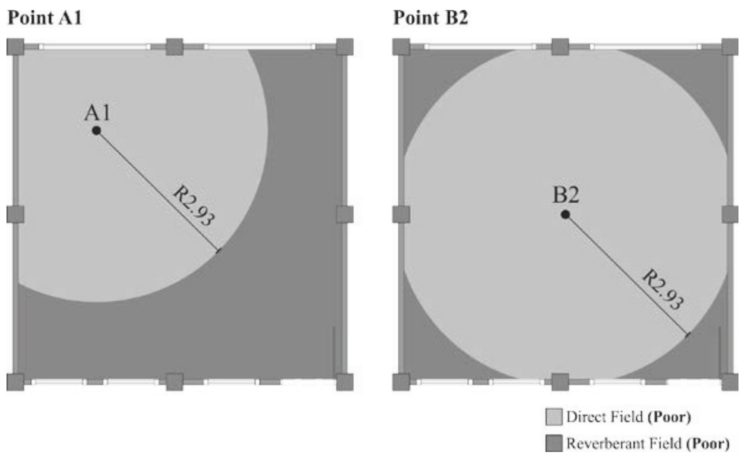

Figure 3. Direct Field and Reverberant Field Direct field according to% ALcons at points A1and B2

3.2. Field Test: Impulse Response Analysis

The data recorded in the field test was carefully analyzed, according to the procedure described on the Methodology. Based on those analyses, the “practical” Reverberation Time (RT) of the evaluated classroom was equivalent to 1.87s, value that exceed both, the standard and the theoretical value.
Afterward, in order to calculate the Speech interference level, the Equivalent sound pressure level (L_{eq}), expressed in decibels (dB(A)), needed to be calculated in each quadrant, and then by applying Equation (2) the L_{SIL} for each point of the grid was calculated. The values obtained in this procedure are showed in Table 4. This Table lists the data obtained in each quadrant by grouping and both emission points. The abbreviation EP is used to indicate the quadrant, in which the source was located. To each cell a color was assigned, based on the qualification that the calculated value of the quadrant has according to the subjective rating scale described in Table 2.

Table 4. Data obtained in each quadrant by grouping and point of emission source. EP is used when the quadrant is the Emission Point.

L_{SIL} values	A1	A2	A3	B1	B2	B3	C1	C2	C3
RCorner	EP	7.87	6.60	9.51	8.42	9.59	8.72	6.66	12.87
RCenter	12.4	9.11	16.26	15.02	EP	12.08	15.76	12.72	13.99
AWCorner	EP	12.01	9.84	15.85	16.10	11.32	15.65	10.63	14.77
AWCenter	10.38	9.87	13.62	11.87	EP	10.16	9.73	9.06	12.28
GCorner	EP	13.44	15.77	14.01	12.03	14.40	14.93	11.74	11.83
GCenter	17.28	14.29	16.21	13.38	EP	17.59	18.38	18.11	15.33

< -6	Insufficient
-6 a -3	Unsatisfactory
-3 a 0	Sufficient
0 a 6	Satisfactory
6 a 12	Good
12 a 18	VeryGood
>18	Excellent

According to the values obtained during the field test analysis process, all quadrants are rated between good and excellent. The rating scaled used, has between two grades, a wide range of values, which may not allow to clearly perceive the changes from one grid point to the other, in other words, one point can be qualified as good, but its value may be closer to very good or, on the contrary, to satisfactory. For this reason, a “zoom in” scale was developed by the evaluation team that consisted in assigning various hues of the color, which represents the main grade, for a better illustration of the changes however small they are.In this way, the figure obtained aided the researchers to better understand the phenomenon, and also to determine the way each quadrant works in relation with the others. The result of this process is shown in Figure 4.

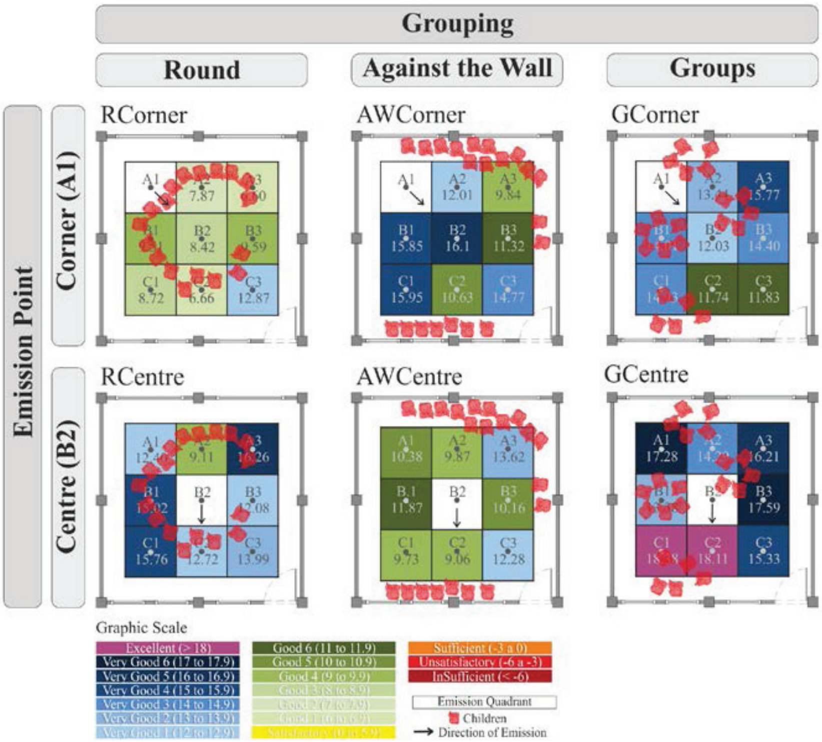

Figure 4. Graphical qualification of intelligibility results for quadrant in each grouping according to the zoom done by the researchers

4. Discussion

Results clearly state that the way the children grouped effectively modified the intelligibility within the evaluated classroom. As shown in Table 4, in all the performed evaluations the quadrants were the microphone was placed, disregarding the children's grouping, were rated between good, very good and excellent. Nevertheless, one point values changes from one of those ratings to another, depending on the grouping/emissionpoint combination. Table 4, allows to observe in parallelall the values obtained by a quadrant in all the cases that were evaluated. For a better understanding of this asseveration, quadrant A2 is taken as an example. This point is valued as *good*in three of the six evaluations (RCorner, RCentreand AWCentre), while in the other three it is rated as very good (AWCorner, GCorner, GCentre). According to that, it is observed that even though the quadrant is never valued by a grade consider undesirable from the point of view of intelligibility, that rating does, in fact,change depending on the grouping.

It can be observed as well, that the modification of the point of emission also had an effect on the quadrant values, and therefore in their color assessment. Taking quadrant A2 again as example, in the same type of grouping, sitting with back against the Wall (AWCornerand AWCentre), when the emission point change from the corner to the center, this quadrant value change from *Very good* to *Good*.

Although in all cases, all quadrants obtained a satisfactory results, there are combinations of grouping/emission point that in an overall evaluation had better results.GCentre in this study, was the grouping/emission point combination that had the best overall rating, being the only one having two quadrants qualified as *excellent*, and the other 6 as *very good*.

According to the point of emission, a classroom with a specific grouping, may present two different sound environments. This information constitutes an important tool the space user, in this case the teacher, that can choose, based on the results, the point of emission from where her instructions will be better understood. For example, when the students are grouped in around table, talking from the center will ensure a better understanding of the emitted message, as most quadrants are valued to have a *very good* intelligibility, and the acoustical environment is both, well qualified and homogeneous.

Regarding the reverberation time, as it was mentioned before, both, the theoretical and the practical, exceeded the upper limit of the standard. When related to their respective intelligibility assessment method, the theoretical qualification of the space intelligibility was coherent with the high reverberation time, in this way, exceeding the limits of the standard will result in a poor intelligibility of the acoustical environment. However, the practical reverberation time waseven higher than the theoretical, and yet the intelligibility qualification of the space was valued as satisfactory, by the SIL method. Even though being two methods of very different nature, both SIL and the %ALCons, evaluate the same parameter, which leaves the question of why such different results were obtained.

5. Conclusion

The intelligibility of the space is affected by the way it is occupied. The way users are grouped, changes the space rating. In the same way, for each one of the grouping forms, there is a recommended emission point, the one that allows both, a better intelligibility and a more homogenous environment, in order to ensure that all students are receiving the massage in the best possible way, and their acoustical comfort is not compromised within the space. Some of the evaluated ways of grouping, such as Groups, showed for both emission points, similar results and a very homogeneous space. According to those results both of the evaluated position could be consider as suitable, since the differences between them are not significant.

The parameters covered by the Colombian technical Standards NTC 4595, do not make significant contributions to the subject of the classrooms intelligibility. Important aspects such as the background noise, the grouping, and the most favourable emission points are not considered. On the other hand, according to the results, a Reverberation Time (practical or theoretical) outside the limits requested by the standards does not necessarily mean a poor space intelligibility.

There are contradictory results between the theoretical and practical method, which means that more studies need to be performed in other classrooms, and other intelligibility assessment methods need to be apply, in order to better understand this phenomenon and to verify and determine if the differences found, were produced by the scale of the space, the particular approach of each method or if they were produced by other reasons.

Acknowledgements

The research team would like to thank the school board, the teachers and students of the Kindergarten “Lunita Clara”, where this study was performed, for their active participation.

To the sound engineersDaniel LondonoGaleano and David Felipe Mejia for theirguidance in the process.

To the Architect Juan Carlos Guerra who participated in the field test.

References

[1] F. E. Rodríguez, “Elementos para el estudio del carácter acústico del espacio arquitectónico.,” *Estud. Arquit. bioclimática*, vol. V, pp. 206–220, 2003.

[2] M. R. Schroeder and T. D. Rossing, *Springer Handbook of Acoustics*. New York: Board, 2007.

[3] F. E. Rodríguez, “Predicciones de las características acústicas en aulas escolares mediante el uso de modelos de simulación por computadora,” *Estud. Arquit. bioclimática*, vol. VII, pp. 146–160, 2005.

[4] A. Carrión Isbert, *Diseño Acústico de Espacios Arquitectónicos.* Barcelona, España: Alfaomega, 2001.

[5] C. González and M. Gómez, “Evaluación de la comunicación verbal: método SIL.,” *Norma técnica prevención 794, Notas Técnicas Prevención*, 2009.

[6] MEN Colombia, *Norma Técnica Colombiana NTC 4595 Ingeniería Civil y Arquitectura. Planeamiento y Diseño de Instalaciones y Ambientes Escolares*, no. 2. 2006, pp. 1–83.

[7] E. Munar, J. Rosselló, C. Mas, P. Morente, and M. Quetgles, “El desarrollo de la audición humana.” Universitat de les Illes Balears, 2006.

[8] A. García Cardona, “Evaluación Bioclimática en Espacios Educativos para Niños de Preescolar a partir de su respuesta ambiental, en climas Templados Andinos en Colombia (In progress),” Instituto Superior Politécnico José Antonio Echeverría - CUJAE.