Energy analysis of techniques and materials used in sound insulation of music rehearsal rooms

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Resumen

En este proyecto se realizó un análisis acústico y de energía de los materiales comúnmente utilizados para el aislamiento acústico de las salas de ensayo de música. El objetivo principal fue identificar el impacto en las ganancias de calor debido al aislamiento de la habitación, y por lo tanto, el aumento resultante de las necesidades de energía de aire acondicionado. El método consistió primero en la construcción de un modelo 3D del actual edificio del College of Music (COM) de la Universidad de San Francisco.

Este modelo se realizó en DesignBuilder. Una vez construido el caso base, se desarrolló un nuevo modelo con una solución de aislamiento acústico eficaz que se denominó "simple". La solución consistió en materiales de aislamiento comunes, de manera que se obtuvo un nuevo requerimiento de energía para la refrigeración, diferentes de la del caso base. Después se realizó otro modelo con una solución que se denominó "compleja" en el que, además de materiales de aislamiento de sonido, se implementó técnicas modernas y elementos mecánicos que eliminan el impacto de ruido y vibraciones. Se obtuvo un nuevo requisito de energía de aire acondicionado, diferente de la del caso base. Una vez que se obtuvieron los diferentes requerimientos de energía, se compararon y finalmente se demostró que aunque la solución "compleja" para el aislamiento acústico implicó una mayor masa térmica esto fue compensado por un coeficiente global de transferencia de calor más alta; por lo tanto, no hay aumento considerable de consumo de energía de aire acondicionado. Como resultado, los costos operativos debido al consumo de energía del aire acondicionado serán los mismos para ambas soluciones.

Palabras clave— Acústica; Aire Acondicionado; Materiales de Construcción; Eficiencia Energética; Aislamiento Acústico.

Abstract

In this project an acoustic and energy analysis of materials commonly used for sound insulation of music rehearsal rooms was performed. The main target was to identify the impact on heat gains due to room insulation, and therefore, the resulting increase of air conditioning energy requirements. The method consisted on first building up a 3D model of the current College of Music (COM) building of the Universidad San Francisco, including construction characteristics like materials, electronic equipment, lighting, metabolic activity of occupants, etc. This model was performed in DesignBuilder, with which heat gains/losses through walls, floor, ceiling, doors, and windows were obtained, in addition to energy requirements of cooling systems. Once the base case was built up, we developed a new model with an effective sound insulation solution that we called "simple". The solution consisted in common insulation materials, such that a new energy requirement for cooling was obtained, different from that of the base case. Later we made another model with a solution that we called "complex" in which, in addition to sound insulation materials, we implemented modern techniques and mechanical elements that eliminated impact noise and vibrations. A new air conditioning energy requirement, different from that of the base case, was also obtained. Once the different energy requirements were obtained, those were compared and finally demonstrated that although the complex solution for sound insulation involved a higher thermal mass this was compensated by a higher overall heat transfer coefficient; therefore, there is no considerable increase in air conditioning energy consumption. As a result, operative costs due to air conditioning energy consumption will be the same for both solutions.

Keywords— Acoustics; air conditioning; construction materials; energy efficiency; sound insulation.

Recibido: 14-12-2015, Aprobado tras revisión: 24-12-2015.
Forma sugerida de citación: Remache, P.; Pantoja, D.; Lozada, P. (2016). "Energy analysis of techniques and materials used in sound insulation of music rehearsal rooms". Revista Técnica ***"energía".*** N º 12, Pp. 367-372. ISSN 1390-5074.

1. INTRODUCTION

Rehearsal rooms are spaces used by musicians to practice and improvise with their bands. These rooms have to be well insulated so that noise cannot escape to other spaces such as along corridors and rooms. Many materials have been designed in order to avoid sound passing through walls, ceilings and openings of these rooms. Although insulation materials avoid sound leakage, these also reduce the value of the overall heat transfer coefficient U [1]. In addition, heat gains in rehearsal rooms include high metabolic rates of musicians, heat dissipation by power supply devices, amplifiers, computers and lighting. All these facts together result in higher indoor temperatures, causing HVAC systems to consume more energy in order to keep thermal comfort [2]. As modern methods for energy analysis have been introduced to the buildings sector, it is extremely recommended, if not compulsory, to first run an analysis over the different options available before implementing a solution. This will allow the engineer or architect to choose not only the best option for sound insulation but also for energy efficiency.

2. METHODOLOGY

According to Wanger Corporation [3] there are four areas of acoustic concern in a rehearsal room: sound insulation, room acoustics, mechanical noise, and practice room acoustics. In this study we analyze the first concern, sound insulation, which is a daily issue in the rehearsal room COM105. This practice room is not well insulated and therefore it is generating high levels of noise to other rehearsal rooms, especially to rooms in the second floor, which are for voice practicing. According to MM. Daniela Guzman, voice teacher of the COM, it is impossible to have singing classes while rehearsal room COM105 is in use. Lambda Acoustics Lab, researching partner, will propose two effective solutions for sound insulation, one that we call "simple" where common materials and techniques are implemented and the other to which we call "complex" where special techniques such as noise impact elimination using mechanical elements are applied. Then, we will build up a 3D model of the building using DesignBuilder, in order to analyze the energy requirements of the rehearsal room for base case, simple and complex solutions. Finally we will compare the three cases to identify the most efficient solution.

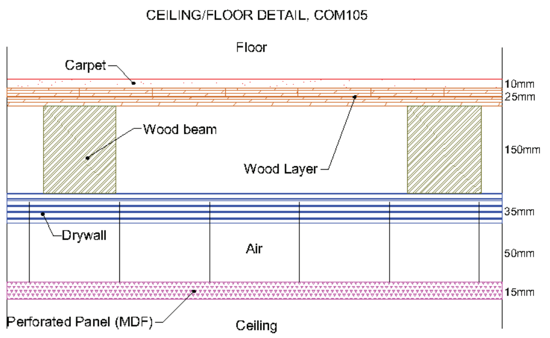
A. Constructions

It is important to first determine the principal components of the rehearsal room and find out if those are or not allowing sound to leak. We will discuss the current situation of ceiling, floor, door, walls, and windows in order to identify sound leakage sources. This will also be used for building up the 3D model of the COM Building in DesignBuilder. The College of Music building was built over the structure of an old house located in front of the Universidad San Francisco, Cumbaya – Ecuador. It keeps the original materials from the walls of the house and combines new materials added to enhance the structural and aesthetic characteristics of the construction.

a) Windows: Double glazed with an air space of 30 mm approximately with excellent tightness in the frames; therefore, sound insulation was effective. However, there was no mechanism to open windows so natural ventilation was not allowed.

b) Doors: Well insulated since a layer of 50 mm of fibreglass was used between two layers of sheet metal of 3mm thickness approximately. Good tightness was kept in the frame thus no sound leakage was found.

c) Ceiling, walls, and partitions: Materials encountered in these components were definitely causing sound to leak. Those were not designed to avoid sound leakage and no insulation material was found. Therefore, ceiling walls and partitions must be replaced or redesigned so that sound cannot escape from the room. The materials used in ceiling, walls and partitions are shown in Figure 1 and the overall heat transfer coefficients in Table 1.



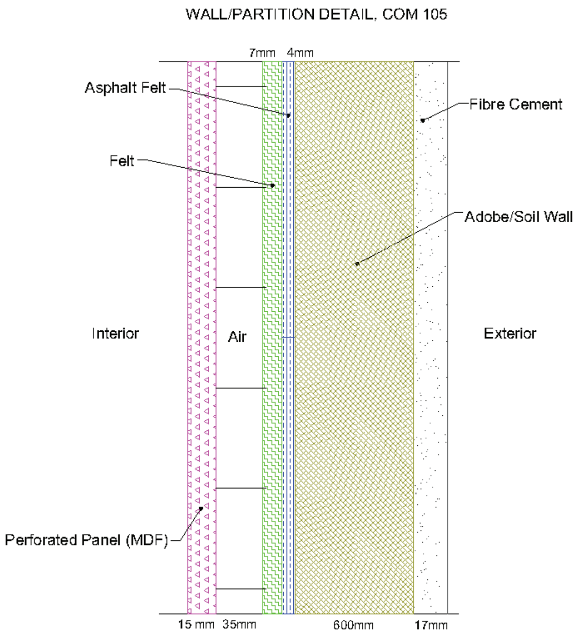


Figure 1: Detail of materials used in ceilings and walls

table 1: overall heat transfer coefficients of current constructions of the college of music building

Construction	U value (W/m2K)
Wall/partition	1.006
Floor/Ceiling	0.79
Windows	2.734
Doors	0.662

B. Base Case Model

The base case model corresponds to the building with current materials. Using the information of constructions just stated above and dimensions obtained from architectural plans the model could be built up. The final base case model is shown in Figure 2. The COM105 classroom has 37.5m2 of floor area. Is used for two purposes, seminars with an average of 27 students attending from Monday to Friday, and rehearsals with bands having up to 7 musicians playing and singing. As there are two different periods during the day with different occupancy, two simulations had to be performed separately in DesignBuilder, one for seminars and one for rehearsals. Occupancy, clothing and metabolic rates are as shown in Table 2.

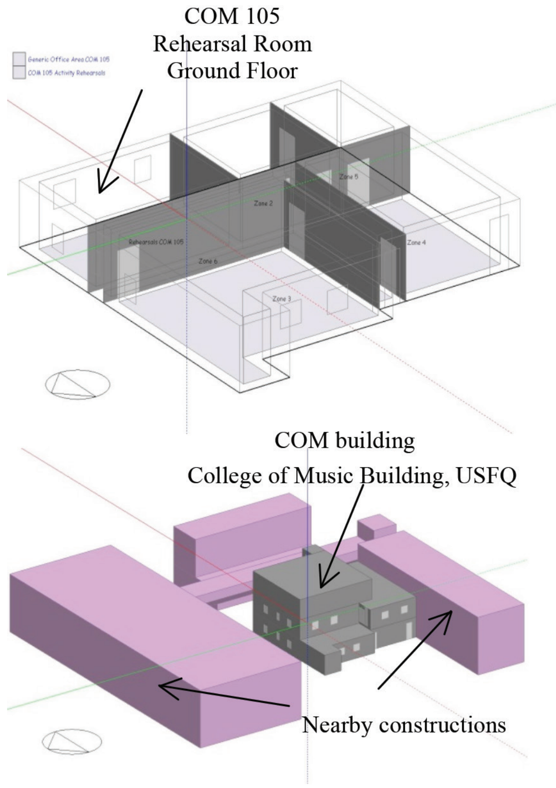


Figure 2: 3D model of the College of Music of the Universidad San Francisco

Table 2: Activity details for classroom COM 105, month of June

Weekday	Schedule	Activity	Metabolic rate (W/ person) [4]	Clothing (clo) [5]	Occupancy (people/m2)
Monday to Friday	8:00 – 14:00	Seminars	147.83	0.57	0.747
	14:00 – 19:00	Rehearsals	203.62	0.57	0.187

To complete the building model, it had to be taken into account the equipment used into the room for amplifying voices, guitars, etc. since those dissipate heat into the room and aid to increase its temperature. In Table 3 are shown all the appliances that generate heat when on.

Table 3: Power of electronic equipment used in the COM 105 classroom

Device	Power (W)	Power by Area (W/m^2)
Guitar Amp	180	4.8
Bass Guitar Amp	400	10.67
Keyboard	30	0.8
Mixer/Amplifier	70	1.87
Laptop	50	1.33
Total	730	19.47

Lighting is also an additional element that generates heat into the room. The COM 105 has 11 fluorescent lamps each with 60W of power. In order to control occupancy through the whole year, schedule profiles had to be created. These schedules allowed to program when the room was occupied, like in a normal semester of classes, or when it was unoccupied, like in holidays. Schedules were also generated to control when equipment was being used and when lighting and HVAC systems were on or off. It is important to mention that the simulations ran using a weather file that was generated from University and local weather stations in a previous project [4].

B. Simple and complex solutions

Once the base case was built up, a new model was developed with a sound insulation solution called "simple" that consisted on the addition of common insulation materials to the base case envelope. Materials used in simple solution are shown in Table 4.

Table 4: Details of Materials used for simple solution

Material	Density (Kg/m³)	Specific Heat (J/kgK)	Conductivity (W/mK)	Thickness (mm)	Purpose
High density vinyl	2200	1000	0.25	3	Sound insulation
Mineral wool	80	840	0.038	50	Sound absorption
Cross-linked polyethylene foam	27	2300	0.04	10	Impact noise elimination

Later, another model was made with a solution called "complex" in which, in addition to sound insulation materials, modern techniques and mechanical elements that eliminate impact noise and vibrations were implemented. This second solution also implies more effective sound insulation results. Materials used in complex solution are shown in Table 5. The forecasted degrees of sound insulation effectiveness for different solutions are shown in Table 6. Overall fabric heat transfer coefficients for different cases are shown in Table 7.

Table 5: Details of materials used for complex solution

Material	Density (Kg/m³)	Specific Heat (J/kg.K)	Conductivity (W/mK)	Thickness (mm)	Purpose
Concrete	2000	1000	1.13	250	Sound insula-tion
Mortar/ cement	1760	840	0.72	17	Sound insula-tion
Ceiling hangers	N/A	N/A	N/A	231	Impact noise elimina-tion

Table 6: Forecasted degree of sound insulation effectiveness

3D building model for energy analysis	Forecasted degree of sound insulation effectiveness
Base case	0%
Simple solution	55%
Complex solution	90%

Table 7: Overall fabric heat transfer coefficients for different cases

Construction	Base case U value (W/m2-K)	Simple solution U value (W/m2-K)	Complex solution U value (W/m2-K)
Wall/partition	1.006	0.431	0.431
Ceiling	0.79	0.352	0.689
Windows	2.734	2.734	2.734
Doors	0.662	0.662	0.662

3. RESULTS

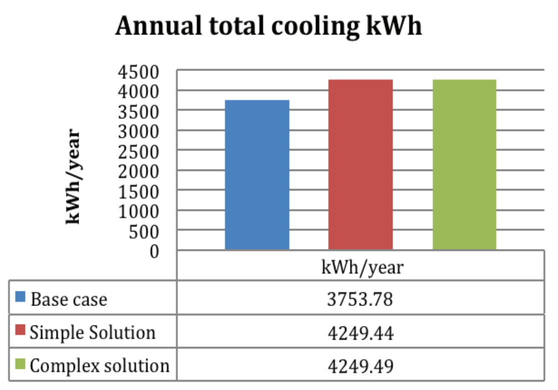
Fabric heat balance shows that there is no difference of heat transfer between both solutions. However heat for both solutions is higher than that of the base case. Resulting fabric heat balances for different cases are shown in Table 8.

Table 8: Annual fabric heat balance for different cases

Case Study	Glazing (kWh)	Walls (kWh)	Ceilings (kWh)	Ground Floors (kWh)	Partitions (kWh)
Base case	-490.78	-2939.55	960.54	-938.51	1328.33
Simple Solution	-559.72	-1405.89	695.75	-1076.59	930.95
Complex solution	-559.79	-1406.04	695.48	-1076.72	933.12

Total cooling requirements for cases simple and complex are extremely similar but there is an increment of 13.21% if compared with the base case. Annual total cooling requirements for different cases are shown in Figure 2.

Fig. 1. Annual total cooling requirements



Increase in annual electricity costs as a result of thermal insulation is presented in Table 9. Total cost is calculated for the mean generation, distribution and transmission costs of the regional electric company (Quito) [5].

Table 9: Annual electricity consumption and costs for different cases

Case study	Annual air conditioning electricity consumption	Electricity cost for regional company	Total annual electricity cost for regional company	Increase in electricity consumption and total electricity cost
	kWh/year	USD c/kWh	USD/year	%
Base case	3753.78	8.073	303.04	N/A
Simple Solution	4249.44		343.06	13.21
Complex Solution	4249.49		343.06	

4. DISCUSSION

It has been demonstrated that although the complex solution for sound insulation involves a higher thermal mass this is compensated by a higher overall heat transfer coefficient; therefore, there is no considerable increase in air conditioning energy consumption. As a result, operative costs due to air conditioning energy consumption will be the same for both solutions. The only differences between both solutions are U values of ceiling, initial investment and sound insulation degree of effectiveness (i.e. the complex solution is more effective for sound insulation). However, the complex solution implies to remove the whole ceiling in order to install the impact noise absorbers while for the simple solution insulation materials are installed directly over the current floor. The resulting increases in energy consumption and electricity costs seem to be not too high (13.21%). However, results would be different and probably considerable if simulations are run for every rehearsal room contained in the building. Different metabolic rates, lighting, occupancy schedules, etc., should be set for each one of the rooms according to University academic calendar, as it has been done for the COM105 rehearsal room. Each rehearsal room has different sound insulation requirements according to sound pressure levels, shape and acoustics of the room, current materials, type of adjoining rooms, etc., thus, individual analysis have to be performed in order to get the best combined results of energy efficiency and sound insulation.

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