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The increment in cost and other parameters to upgrade quality classes in sound insulation

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ABSTRACT

Providing comfortable environments for users is the main objective for architects at the design process today. Physical performance parameters of building elements such as sound insulation, thermal insulation, resistance to fire and moisture are evaluated primarily for user comfort. However, in design phase, elements' costs, thicknesses and weights are considered as well. To ensure sound insulation, according to Acoustic Regulation of Turkey, minimum quality class of C should be provided. Practices like adding layer or increasing weight to upgrade quality class from C to A or B, generally are in conflict with the cost criterion. In this study, 509 number of internal masonry wall alternatives made of brick and autoclaved aerated concrete blocks are evaluated. This paper presents results of the calculation of required increments as percentages in cost, thickness and weight to upgrade quality classes.

Keywords: Quality Class, Sound Insulation, Cost

1. INTRODUCTION

The construction sector in the world is growing every year. By the year 2025, it is estimated that the ratio of the construction sector in the total economy will reach 10% in developed countries and 17% in developing countries (1). So far, the growth in constructions has led to many environmental problems and has increased the need for sustainable building design.

Sustainable buildings focus mainly on energy conservation and improvement of the quality of buildings for occupants. User comfort, which can be defined as the state of wellbeing amongst building users, is achieved by controlling factors such as heat, light, sound, water and fire. Selection and use of proper building materials is very important in providing these parameters (2).

To ensure sound insulation in Turkey, "Regulation on Protection of Buildings Against Noise" was published on 31 May 2017 by Turkish Ministry of Environment and Urbanization. The regulation categorizes acoustical performance of buildings and specifies the limit values in terms of 6 parameters: airborne sound insulation, impact sound insulation, façade sound insulation, indoor background noise, mechanical noise and reverberation time. For each parameter, the limit values are defined, according to acoustical performance class ranging from A to F. Every building should comply with minimum requirements. For new buildings, at least C acoustic performance class should be provided. For buildings aiming A or B acoustic performance class, "Acoustic Performance Certificate" is a compulsory document that is used to evaluate and certify acoustic conditions of the building (3).

To upgrade from C to B or A classes and to obtain this certificate, making improvement is necessary primarily at the airborne sound insulation performance of the building elements. For improving sound insulation, general principles can be summarized as 1- increasing mass&density by means of increase in thickness 2- designing double wall 3-providing flexible connections 4- introducing an air gap between layers 5- increasing the air gap thicknesses 6- using porous elements in the cavity 7- avoiding factors that will form a sound bridge between walls, such as insulating the connection points of the elements like service pipes, ducts passing through the walls etc. (4).

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However, in decision phase, effect of these applications on other design parameters should also be taken into consideration. Firstly, these practices affect "cost" which is another important criterion in evaluating the function of a building. Considering that resources are limited, minimizing cost should always be the main objective for projects. Secondly, additional layers added to building elements increase weight. But, designing lightweight buildings is important in Turkey since 92% of the country is in earthquake zones (5). Lightweight wall materials decrease pressure on load-bearing system and increase resistance to earthquake. Thirdly, designing thicker walls to increase sound insulation performance both increase unit cost and the weights. It changes heat gains and losses in buildings and affects their energy consumption as well. For this reason, determination of the optimum thickness is important in design.

This paper examines the effect of improvement in sound insulation performance of walls on cost, weight and thickness criteria by generating basic wall alternatives between two rooms (source and receiver rooms) and calculating values of all criteria. Finally, increment in cost, weight and thickness parameters depending on the change in the sound insulation performance corresponding to acoustical performance classes were evaluated statistically.

2. METHODOLOGY

2.1 Criteria, Objectives and Limit Values

According to Building Census by Turkish Statistical Institute, 75% of total buildings are used as housing. In addition, 51% of total buildings are built in masonry, 48.4%, frame system, and 0,6% other construction systems (6). So, in this study residential buildings with masonry walls are studied. Airborne sound insulation performance was calculated at the partition wall between bedroom of a simple residential building (receiver room) and an adjacent room (source room). Volume of the receiver room is considered as 50 m^3 as specified in the ISO 10140-5 standard. According to this standard, wall dimensions should be approximately 10 m^2 (7). Therefore, wall dimensions were taken as length (l): 4 m, height (h) 2,7 m, and area (a) 10,8 m^2.

Sound and receiver rooms have been considered to have equal internal temperatures. So, thermal insulation and condensation parameters have not been analyzed. For protection against fire, in order to be in compliance with "Regulation on Fire Protection in Buildings" all construction elements were selected as Class A1 non-combustible material (8).

Wall types and building materials were selected so as to be the most widely used types and materials in Turkey. Sound insulation performance ($D_{nT,A}$, dB), cost (Euro/m^2), weight (kN/m^2), and thickness (cm) criteria of the walls were calculated and discussed.

2.1.1 Airborne Sound Insulation

Minimum airborne sound insulation values to be provided according to source and receiver room specifications ($D_{nT,A}$, dB) are determined in "Regulation on Protection of Buildings against Noise" given at Table 1 (4). According to Table 1, first, buildings are categorized according to their noise sensitivity and noisiness. Then, sound insulation values are defined according to the combinations of different levels of noisiness and sensitivity. In this study, receiver room properties were selected as a residential bedroom that is highly sensitive to noise (Degree I) and adjacent source room is regarded as moderate noisy (MN). In this combination, the limit values are 52 dB for C-Class, 58 dB for B-Class and 62 dB for A-Class.

$D_{nT,A}$ value was obtained from the following formula (9)

$$D_{nT,A} = D_{nT,w} + C \quad \text{dB} \tag{1}$$

and

$$D_{nT,w} = R'_w + 10\log\left(\frac{0.16\,V}{T_0 S_s}\right) = R'_w + 10\log\left(\frac{0.32\,V}{S_s}\right) \quad \text{dB} \tag{2}$$

where

S_s: Area of partition wall, m^2

T_0 : Reference reverberation time (0.5s for houses)

V: Volume of receiver room, m^3

and

$$R'_w = R_w - C_F \tag{3}$$

C_F: Correction value is calculated by the ratio of the unit weight of partition element (X) to average unit weight of all elements causing flanking transmissions (Y). For x=X/Y then CF value is obtained according to Table 2.

Table 1 –Minimum airborne sound insulation values to be provided according to source and receiver room specifications ($D_{nT,A}$, dB) (4). Limits for MN-I

Source Room Noisiness Level	Receiver Room Sensitivity Level	Acoustical Performance Class					
		A	B	C	D	E	F
High Level of	I - high	68	64	58	54	50	46
Noisiness (HN)	II – moderate	65	61	55	51	47	43
$L_{AF,max} > 75$ dB	III - low	62	58	52	48	44	40
Moderate	I - high	62	58	52	48	44	40
Noisiness (MN)	II – moderate	59	55	49	45	41	37
$75 \geq L_{AF,max} > 55$ dB	III - low	56	52	46	42	38	34
Low Level of	I - high	56	52	46	42	38	34
Noisiness (LN)	II – moderate	53	49	43	39	35	31
$L_{AF,max} \leq 55$ dB	III - low	50	46	40	36	32	28

Table 2 – C_F : correction value (9)

x	x≤1	1<x≤2	2<x≤3	3<x
C_F	0	2	4	6

In order to determine R_w (C; C_{tr}) values, INSUL sound insulation prediction software has been used. INSUL is based on models created by applying mass law theory that takes into account the critical frequency and approaches developed by B.H. Sharp, Cremer, Fahy, Ljunggren, Rindel and others. It has been noted that the program reliably predicts sound insulation values with a 3-5 dB approximation (10).

In the calculation of C_F values, it was accepted that unit weights of the walls are equal. The lower and upper floors were considered as 15 cm reinforced concrete.

2.1.2 Cost

In Turkey, for construction cost estimation, “Construction Unit Price Methodology” by The Ministry of Environment and Urbanism is widely used. Within the scope of construction unit price method; inputs of unit price are labor, machinery-equipment and material. A short description of the work for each of the inputs (laborer, mason etc.), machinery-equipment (excavator, bulldozer etc.) and material (brick, sand, cement etc.) are listed, unit and unit price of the work has been determined with a code number given in the Construction and Installation Unit Prices Book (11). An example of a unit price cost estimation is given at Table 3. Values were calculated in Turkish Lira (TRY) at first and then converted into Euro (EUR) (12).

2.1.3 Weight

Loads than can act upon a structure are generally classified as permanent (dead) loads, imposed (live) loads, horizontal loads and other loads such as load caused by temperature difference. Dead loads refer to the structure's self-weight and generally remain constant during the structure's life. Live loads, such as traffic loads may vary. Earthquake load and wind load are example to horizontal loads. In this study, only permanent-self loads of the non-load bearing walls were calculated. Total load of the wall is calculated as the sum of all elements' weight constituting the wall such as block, mortar, plaster, steel studs, rockwool, gypsum board etc.

2.2 Creating Non-Load Bearing Masonry Internal Wall Alternatives

Generating wall types were started with the design of a single wall. Afterwards, alternatives were multiplied considering the general principles for improving sound insulation such as increasing mass&density by means of increase in thickness, adding layer, designing double wall, introducing an air gap between layers, increasing the air gap thicknesses and using porous elements in the cavity.

Table 3 – Example of unit cost calculation (11)

Item No	Analysis Name				Unit
15.220.1003	Building walls using 200-mm horizontally perforated bricks				m^2
Item No	Definition	Unit of Measure	Quantity	Unit Price	Amount (TRY)
	Material:				
10.130.2010	250 x 250 x200-mm horizontally perforated bricks (Including losses)	Qty	15,00	1,06	15,90
19.100.2416	Preparing lime mortar (with slaked lime bags)	m^3	0,018	141,40	2,55
10.130.9991	Water	m^3	0,01	6,84	0,07
	Labor:				
10.100.1013	Master bricklayer	h	0,68	15,70	10,68
10.100.1062	Unskilled worker (Construction worker) (Including loading, horizontal and vertical handling unloading at the construction site)	h	1,36	11,50	15,64
	Material + Labor Cost:				44,84
	25% contractor's profit and overheads				11,21
	Price per m^2				56,05 [(1)]

[(1)] 53,29 TRY=7,89 Euro (21 May- CBRT Exchange Rates)(12)

Alternatives are presented in the Table 4 below. Paint application on wall is not included in the study because it depends on the subjective preferences in projects.

2.3 Building Materials

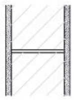
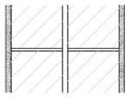
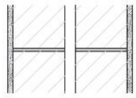
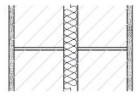
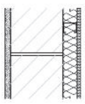
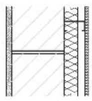
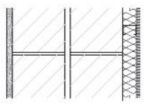
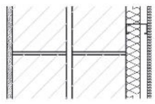
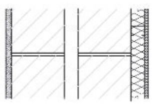
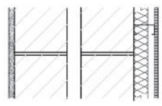
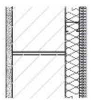
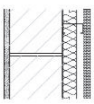
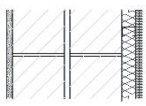
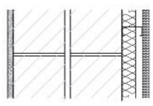
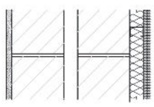
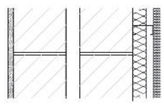
In Turkey, according to Building Census, most commonly used infilling wall material is specified as brick for masonry buildings (6). In addition, Turkey is one of the biggest global AAC producers in Europe (13). Therefore, brick and AAC blocks were preferred as wall materials for the study. Bricks used in this study are categorized in EN 771-1 as clay masonry units with LD (low gross dry density) and Category I (Level of confidence). Type of bricks are vertically perforated (VP), horizontally perforated (HP) Class-AB, horizontally perforated (HP) Class-W (14). AAC blocks were selected as non-reinforced blocks in EN 771-4 (15).

In determination of the thicknesses and densities, Unit Price Book of the Ministry of Environment and Urbanization has been taken into consideration which gives information about the most produced materials (11). Since the target is to provide minimum wall thickness, blocks larger than 15 cm were not calculated for double walls. Densities and thicknesses for the bricks and AAC blocks are given in Table 6. Other properties were considered as following: Elasticity Modules (E, GPa): 2,5 for HP, 3 for VP-650kg/m^3, 4 for 750kg/m^3,1,75 for AAC 400 kg/m^3, 2,25 for AAC 500 kg/m^3 and 2,75 for AAC 600kg/m^3. Loss factors are 0,01 for both bricks and AAC blocks. Poisson's Ratio's (σ) are 0,25 for both bricks and AAC blocks. Properties of the other materials are: Gypsum board: 1,25 cm - 640 kg/m^3, Rockwool: 5 cm 50kg/m^3, Cement Plaster: 2 cm 2000 kg/m^3, Brick Mortar: Lime Cement Mortar-1800 kg/m^3. For AAC Block instead of mortar, special adhesive is used.

2.4 Calculation of Number of Alternatives

Regarding the multiplication of the number of density and number of thickness, it is calculated that number of alternatives are 60 for Type 1, 19 for Type 2a, 19 for Type 2b, 19 for Type 2c, 240 for Type 3, 152 for Type 4. Therefore, total amount of calculated walls is 509.

Table 4 – Internal wall alternatives

Alternatives					
Type 1 (1) Single Wall		Type 2(1) Double Wall			
		 a) 2 cm airgap		 b) 5 cm airgap	 c) 5 cm Rockwool
Type 3 (2) (3) Single Wall+ Wall Lining		Type 4 (2) (3) Double Wall+ Wall Lining			
 5-G	 7,5-G	 a-5-G	 a-7,5-G	 b-5-G	 b-7,5-G
 5-2G	 7,5-2G	 a-5-2G	 a-7,5-2G	 b-5-2G	 b-7,5-2G

(1) Cement plaster on two side
(2) Cement plaster on one side
(3) 5 - G: 5 cm rockwool in 5 cm airgap + single layer gypsum board
7,5 - G: 5 cm rockwool in 7.5 cm airgap + single layer gypsum board
5 - 2G: 5 cm rockwool in 5 cm airgap + double layer gypsum board
7,5 - 2G: 5 cm rockwool in 7.5 cm airgap + double layer gypsum board
with DU50 or 75 and DC50 or 75 metal cladding profiles

Table 5 –Properties of the materials

Material	Code		Dry Density (kg/m^3)	Thickness (cm)	
					(Not calculated for double walls)
Brick	HP		600	10 - 12 - 13,5	19 - 20 - 24 – 25
	VP	W	650 - 750	11,5 - 14,5	17,5 - 19 - 24 - 25 - 30
		AB		-	19 - 24 - 29
AAC	AAC		400 - 500 -600	10 - 12,5 - 13,5 - 15	17,5 - 19 - 20 - 22,5 - 25 - 30 - 35

3. RESULTS OF THE STUDY

According to the sound insulation calculations, 54 wall types were found to be < 52 dB – the limit for C-Class and excluded from the analysis. Thus, number of 455 walls were analyzed. Of the 455 walls, it was calculated that, 84 number of walls were in Class C, 136 number of walls were in Class B and 235 number of walls were in Class A.

Statistical analysis of the data has been performed by using IBM SPSS 25 (Statistical Package for Social Sciences) (16). Evaluations were made for determining relationships between criteria of the study using Spearman's correlation. Table 6 points out Spearman's correlations for all variables. All the correlations have 455 sample size (N) and they all have 2-tailed 0.01 level significance. Considering the correlation coefficient is weak for 0.1-0.29 moderate for 0.3-0.49 and strong for 0.5-1,0 values; looking at the Table 6, it can be confirmed that, between all variables there appears to be a strong positive correlation except the correlation between sound insulation and weight which is moderate.

Table 6 –Spearman 's correlations for data

Variable 1	Variable 2	Correlation Coefficient [(1)]
Sound Insulation (D_{nTA} – dB)	Cost (Euro/m^2)	0,695
Sound Insulation (D_{nTA} – dB)	Thickness (cm)	0,688
Sound Insulation (D_{nTA} – dB)	Weight (kN)	0,395
Cost (Euro/m^2)	Thickness (cm)	0,832
Cost (Euro/m^2)	Weight (kN)	0,538
Thickness (cm)	Weight (kN)	0,785

[(1)]All the correlations are significant at the 0.01 level (2-tailed).

Besides, variation of cost (Euro/m^2) weight (kN/m^2) and wall thickness (cm) related to airborne sound insulation values of acoustical performance classes (D_{nTA} - dB) for MN-I combination has been examined. Minimum, maximum, range, mean, median, std. deviation values were calculated for each class for all criteria. Results of the calculations are given in Table 7 and graphs of the analysis are presented at Figure 1-3. Figures illustrate min, max and median values depending on the parameter corresponding each of the sound insulation performance value.

When Table 7 is evaluated, mean (average) and median values are found to be close to each other. Analyzing the median values, it can be specified that, in order to upgrade classes, the required increment is, for cost criterion, from C-Class to B-Class 3,1%, from B to A 23,2 and from C to A 27%; for weight criterion, from C-Class to B-Class -6,4 % from B to A 24,3 % and from C to A 16,3% ; for thickness criterion, from C-Class to B-Class 4,4% and from B to A 29,7 %, from C to A 35,4%.

These results demonstrate that for MN-I combinations, with the wall alternatives taken in this study, upgrading from C to B Class requires less than 5% increment. But transition to A Class from C or B requires increment more than approximately 20% for cost, %15 for weight and %30 for thickness.

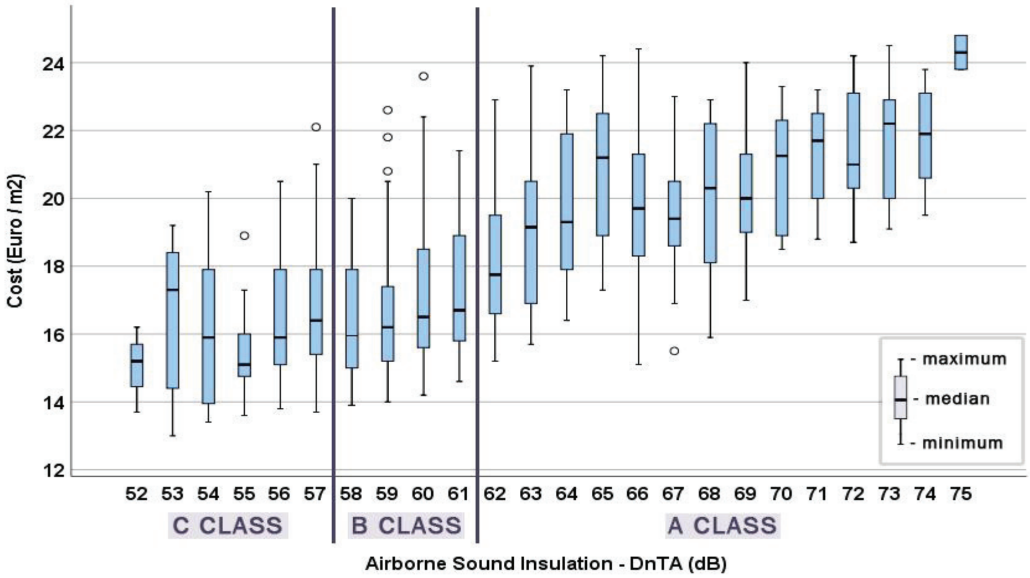


Figure 1 – Variation of cost (Euro/m^2) related to airborne sound insulation values of acoustical performance classes (D_{nTA} - dB) (for MN-I combination)

4. CONCLUSIONS

To provide sound insulation in buildings, sound insulation performances of building elements should ensure the limit values of the Acoustic Regulation of Turkey. Limit values are classified

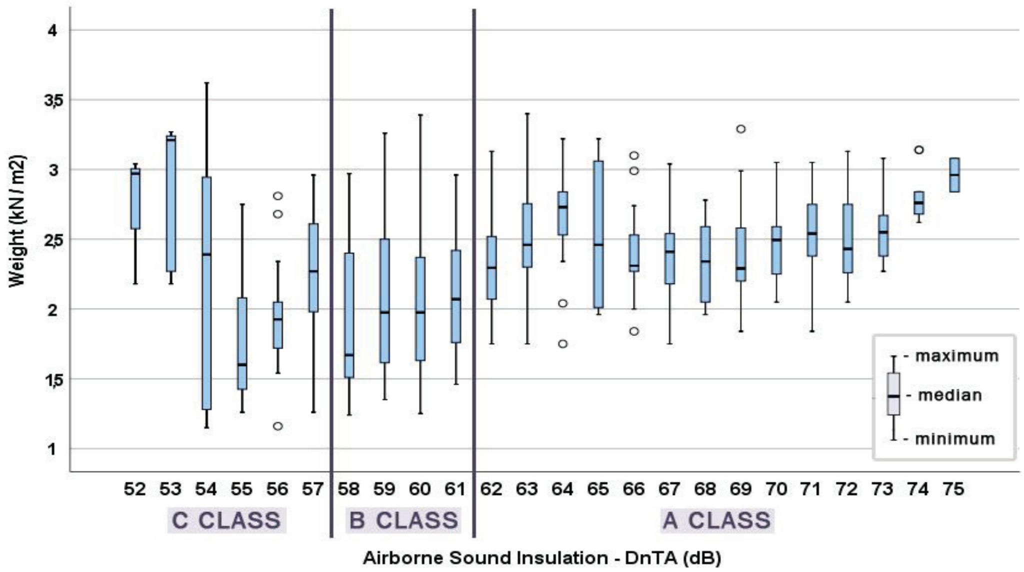


Figure 2 – Variation of weight (kN/m^2) related to airborne sound insulation values of acoustical performance classes (D_{nTA} - dB) (for MN-I combination)

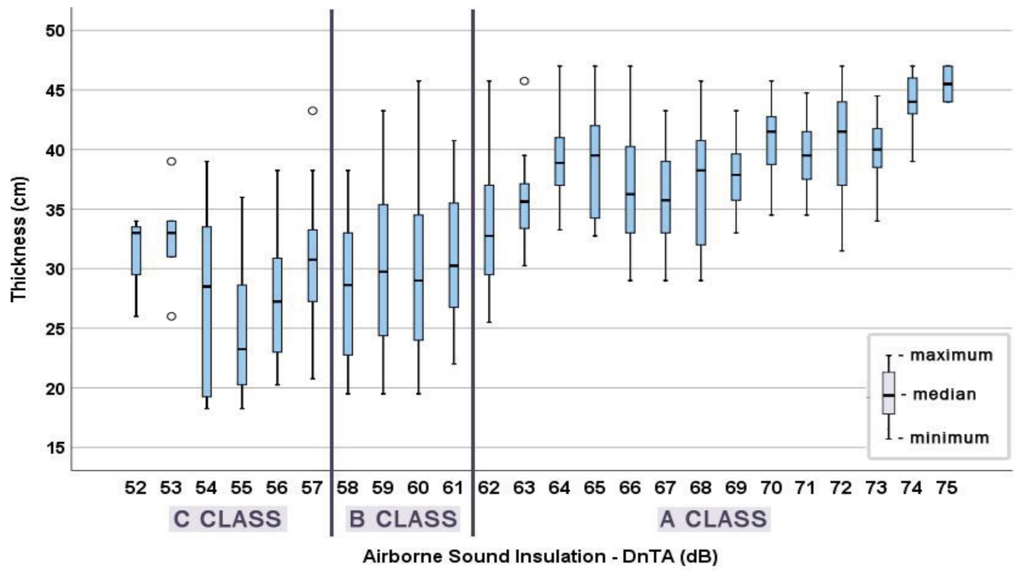


Figure 3 – Variation of wall thickness (cm) related to airborne sound insulation values of acoustical performance classes (D_{nTA} - dB) (for MN-I combination)

according to acoustical performances classes, between A to F. For new buildings minimum C Class is required. Acoustic Performance Certificate will be prepared for buildings performing A or B Classes. Modifications in building elements to provide or enhance sound insulation affect other important parameters such as cost, weight and thickness.

In this study, 509 non-load bearing brick and AAC block wall alternatives were created between source and receiver rooms. Insulation limits for walls were specified considering source room is high sensitive to noise (degree I) and receiver room is moderate noisy (MN). Wall alternatives were formed as single wall, double wall and walls with cladding. After all parameters were calculated, 54 of the walls were eliminated for having lower values than the C-Class limits. As a result, 455 of the walls were evaluated statistically. Between parameters, high correlation has been observed with the Spearman's correlations. In addition, required increments as percentages in cost, thickness and weight to upgrade quality classes has been calculated and analyzed. Results indicate that, for limits of MN-I combination, to upgrade from C-Class to B-Class average of approximately 5% increment is necessary for all parameters. However, upgrading to A Class from C or B requires average of approximately more than 20% for cost, %15 for weight and %30 for thickness. Further studies are required to evaluate the change of parameters for other combinations of noisiness and sensitivity.

Table 7 – Statistical analysis of each class

Criteria	Class	Minimum	Maximum	Range	Mean	Median	*Std. Dev.*
Sound Insulation (D_{nTA} - dB)	C	52	57	5	55,61	56,00	*1,389*
	B	58	61	3	59,68	60	*1,039*
	A	62	75	13	67,49	67	*4,047*
Cost (Euro/m^2)	C	13,0	22,1	9,1	16,3	15,9	*1,9*
	B	13,9	23,6	9,7	16,9	16,4	*2,0*
	A	15,1	24,8	9,7	20,2	20,2	*2,4*
Weight (kN/m^2)	C	1,07	3,35	2,28	1,95	1,96	*0,54*
	B	1,15	3,14	1,99	1,89	1,84	*0,47*
	A	1,62	3,15	1,53	2,31	2,28	*0,34*
Thickness (cm)	C	18,00	43,00	25,00	28,18	28,25	*5,77*
	B	20,00	46,00	26,00	29,62	29,50	*5,95*
	A	25,50	47,00	22,00	38,08	38,25	*4,84*

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