

# Sound Insulation Performance of Prefabricated Concrete Wall Partitions In School Buildings In Athens.

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## Abstract

The scope of this study is to investigate flanking noise transmission through joints between prefabricated concrete elements in School buildings; such joints apparently are not found in the wholesome structure of ordinary concrete buildings. Sound insulation measurements in a prefabricated concrete building of the cell type, were carried out in Athens. This type of prefabrication involves demountable/reusable concrete elements (the cells), which makes critical the question of flanking noise transmission at joints. A sample of seven dividing partitions of classrooms were tested. Sound insulation was also predicted using classical prediction model. Analysis of the measured data leads to useful results about the field acoustic performance of prefabricated concrete wall partitions. The importance of meticulous sealing at joints is also demonstrated.

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## 1. Introduction

Freedom from noise is a significant design parameter for the environmentally friendly educational workplace, and determines considerably construction detailing. Indeed, in school classrooms it is essential to reach adequate ratings of sound insulation for dividing walls, and control flanking transmission paths.

With the introduction of prefabricated concrete buildings in the post war Greece, a trend for school buildings of this type is established. Relative advantages are described in section 2 below. Nevertheless, unlike ordinary concrete buildings which are made up of wholesome(monolithic) structure, prefabricated buildings are set up of jointed building elements (Fig.1,2). This can be a limiting factor for the sound insulation ratings achieved, since joints are potential paths of flanking transmission (Fig.3). This limitation apparently can be even more pronounced with joints of demountable/reusable prefabricated building elements. Such type of school buildings

have been developed by the Hellenic educational authorities since the beginning of the new millennium, and offer the advantage of feasible building relocation whenever this is called for; for instance with fast changing densities of population, after earthquakes, etc. The aim of the present study is to determine the sound insulation performance of concrete wall partitions in school buildings of the said type, in Athens.

## 2. Prefabricated concrete buildings

The notion of prefabricated buildings dates back to antiquity [1]. However, modern building prefabrication evolved rapidly only after World War II. Ruined buildings and cities after war bombing, called for mass production of housing and public buildings such as schools, hospitals etc. [2]. Nevertheless, there was also an additional merit in prefabricated buildings that made these popular; namely that a steady job throughout year was given rise in the construction sector, compared with relative inconvenience of constantly changing construction site [3]. Surveys from European countries and the US suggest that, by and large a 40% of houses are of prefabricated concrete.

Indeed, despite preference for low-cost wooden dwellings, concrete is particularly prevalent in areas that had been affected by adverse weather conditions. [4]

Prefabricated concrete industrial buildings were launched in the Hellenic market since the 1960's. In the 1990's the Hellenic Association of Concrete Prefabrication Industries was established [5]; whilst, the big earthquake of year 1999, gave an impetus for mass production of prefabricated concrete housing and public buildings and the development of formal regulatory framework.

The Hellenic Organisation of School Buildings (OΣK) founded in 1973, also has played an important role in the industry of prefabricated concrete buildings in Greece [6]. Initially OΣK, was using a combination of prefabricated concrete elements (slabs, beams, columns) and concrete elements which were made in situ [7]. However, since year 1985, OΣK has developed the system of prefabricated concrete cells; this involves concrete boxes, namely the cells (Fig.1), which can easily be combined with each other in situ to form classrooms (Fig.2, and Section 4 below) thus saving considerably construction time. This system soon was extended to produce two storey school buildings that suit needs of a lot of regions in Greece, with possibility for demounting and reusing the units at distinct locations [6]. Besides, in terms of sustainability, there are low initial energy costs for production, high thermal mass, fire resistance, cement recycling, ease in packing for transportation, designed to be reusable and finally suitable for use on contaminated soils [4].

The cell type concrete prefabrication has been extensively applied in Greece since year 2003, as well as it has been environmentally improved [7]. Within this context, checking the acoustical performance of this system, both for room acoustics and freedom from noise, is also worth trying.

### 3.Review of past work

The importance of proper acoustic environment in school classrooms has been acknowledged by researchers and relevant scientific research has been carried out over the past few decades; reference has been made both to room acoustics

for classrooms [8,9,10] and to noise protection issues [11,12,13]. Nevertheless, only scanty efforts have been made to investigate the acoustics of prefabricated concrete buildings [14]. In the present authors knowledge no study has been



Figure 1. Prefabricated concrete cell [15]

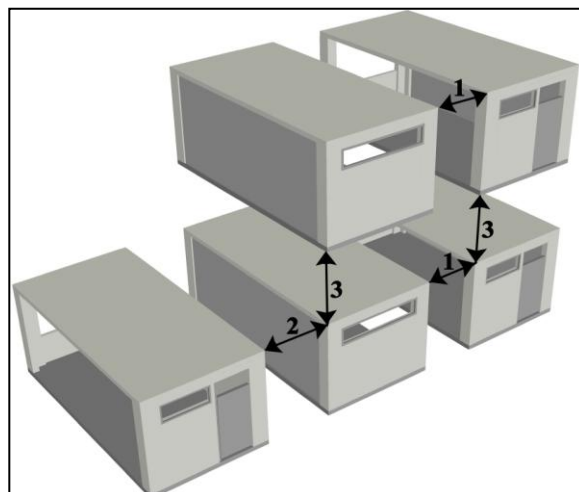


Figure 2. Prefabricated cell combinations. 1) Joint within classroom, 2) Joint between adjacent classrooms, 3) Joint between superimposed classrooms.

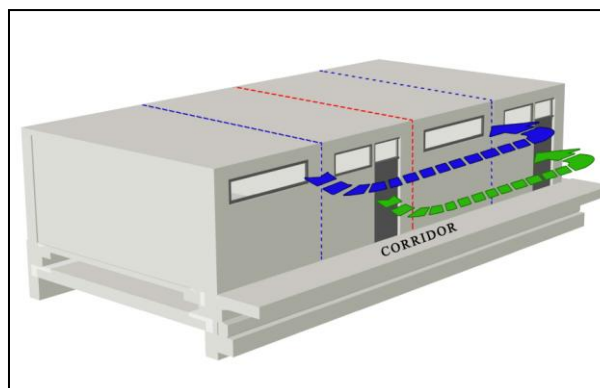


Figure 3. Flanking transmission paths.

- Joint within classroom (see Fig. 3)
- Joint between classrooms (dividing partition) (see Fig. 3)
- Doors or window openings

reported in the literature concerning the sound insulation performance of prefabricated concrete building elements.

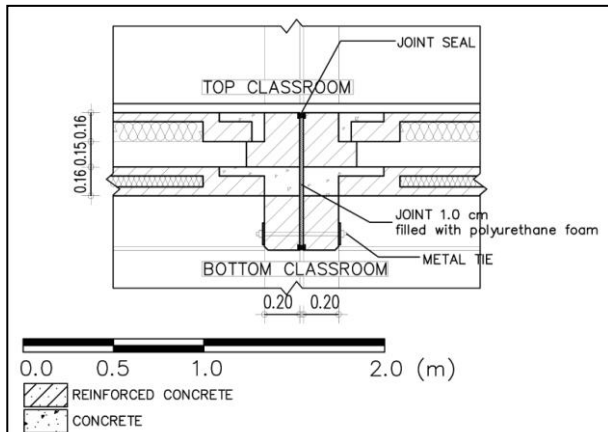


Figure 4. Drawing detail at the joint between prefabricated cells (Joint within classroom).

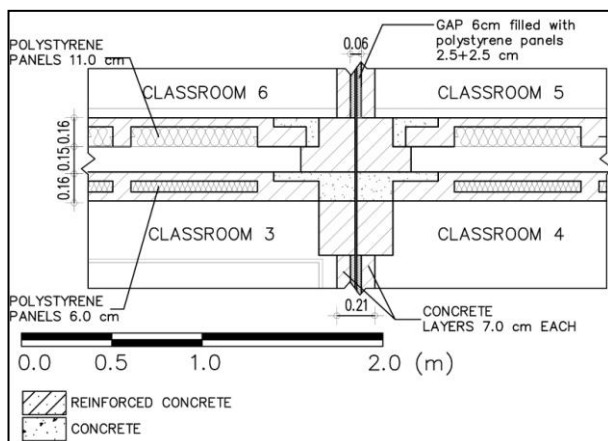


Figure 5. Drawing detail at the joint between adjacent classrooms (partition Type A), and at the joint between superimposed classrooms (slab / partition Type C). *Metal ties at the perimeter of partitions at fixed locations, are unavoidable for structural purposes, albeit they encourage sound bridges.*

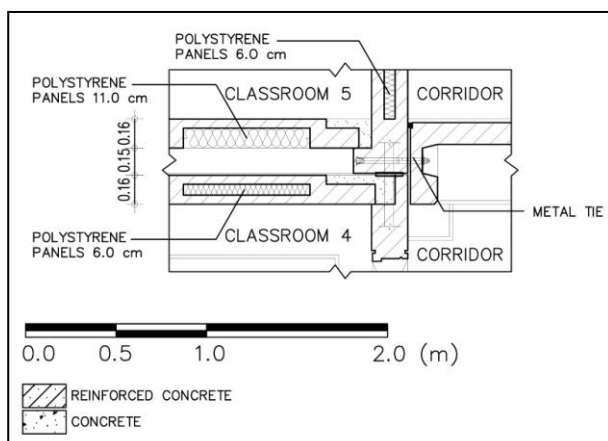


Figure 6. Drawing detail of concrete slab (partition Type C) at the junction with corridor.

#### 4. Experimental design and procedure

This study is concerned with two-storey school buildings of prefabricated concrete of the *cell type* (Fig. 1). In each floor, cells are placed side by side in two ways as illustrated in Fig.2; cells are also superimposed.

When two cells are jointed together (Fig.2, case 1) the resulting joint is 1.0 cm wide and it is sealed with polyurethane foam so as to be air-and-water proof. A resilient (elastomeric) seal is employed at the finish (Fig. 4).

Another type of joint between the two cells occurs between classrooms (Fig.2, case 2); the resulting cavity partition is illustrated in Fig.5. The gap is 6.0 cm wide. This is filled with polystyrene panels, so that in the end a 1.0 cm air gap is left between adjacent cells (Fig.5).

The last type of joint between cells occurs between superimposed classrooms (Fig.2, case 3). The resulting cavity floor is illustrated in Fig. 6. A 15.0 cm air gap between the slab of the top cell (floor) and the slab of the bottom cell (ceiling) is created.

One school building was employed in the present measurements, namely the primary school in Gerakas; the latter is a relatively quiet suburb of Athens (Table I). The selected building is typical of the cell type prefabricated concrete school. Measurements of airborne sound insulation of concrete partitions were carried out. Three types of dividing partitions were tested, and they are shown in Table II. The test partitions are shown in plans and section in Fig.7 and 8 respectively. Typical measuring layout is shown in Fig. 9.

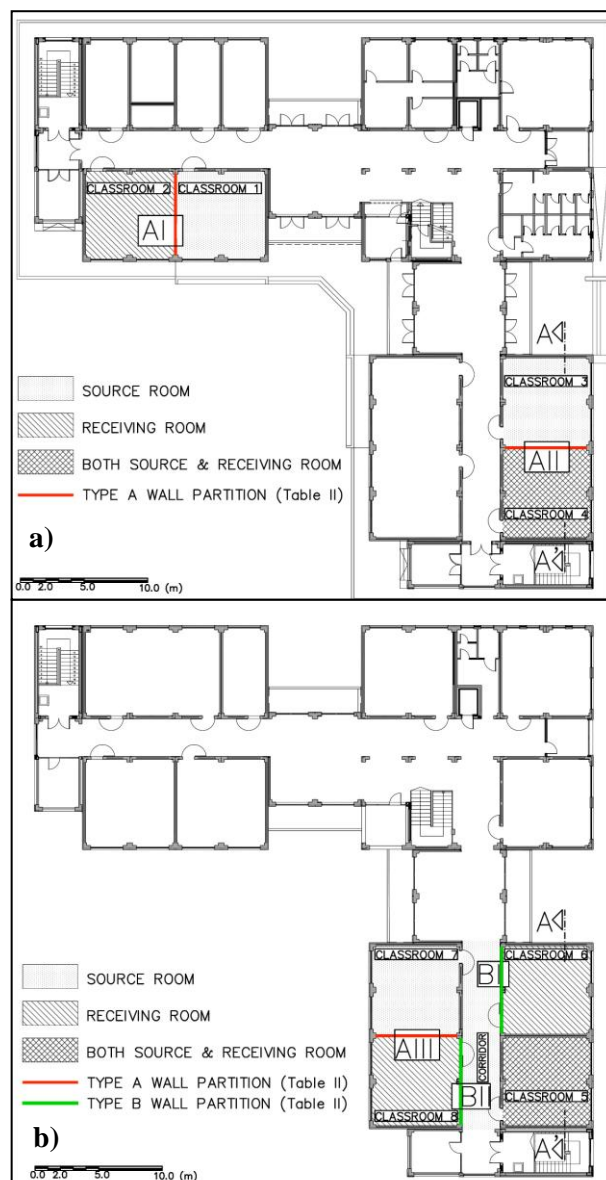
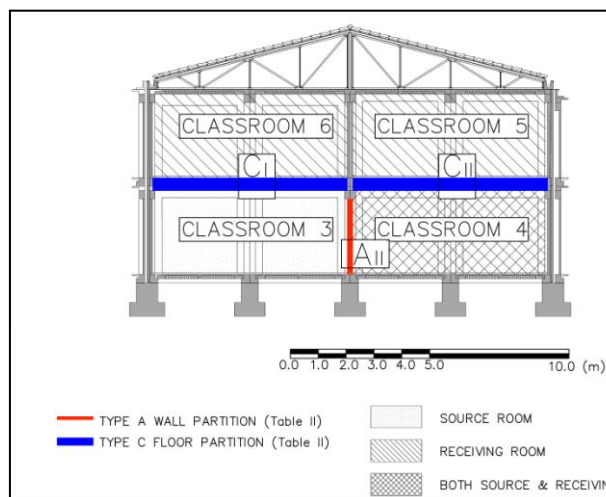
Field measurements were carried out in 1/3 octave bands from 100 Hz to 3150 Hz according to ISO 140/4-1978 standard part 4 in unoccupied classrooms. Acoustic equipment involved a sound level meter 'Hand-held Analyzer Type 2270', a microphone '4189', a loudspeaker 'Omni Power 4296' and a sound amplifier 'LAB.GRUPPEN 2716' (all by Brüel & Kjær).

Table I. Basic details of the test building.

<b>Project</b>	Two-storey school building of prefabricated concrete, in Gerakas Athens, "Hellenic Organisation of School Buildings" (ΟΣΚ)
<b>Year of completion</b>	2010
<b>Design team</b>	<i>Architects:</i> Lady D. Kopana, <i>Structural engineers:</i> H. Zotalis, G. Manolatos, S. Tsoukantas. <i>Mechanical/Electrical engineers:</i> M. Sinni, V. Serbetoglou <i>Acoustical consultants:</i> -
<b>Use</b>	School buildings using demountable prefabricated concrete cells.
<b>Capacity</b>	Max 300 pupils

Table II. Types of test partitions and samples.

TEST PARTITIONS		
Type	Description	Sample
<b>A</b>	Cavity partition between classrooms (see Fig.4)	A <sub>I</sub> , A <sub>II</sub> , A <sub>III</sub> (see Fig.7)
<b>B</b>	Cavity composite partition between classroom and corridor. (see Fig. 2,5)	B <sub>I</sub> , B <sub>II</sub> (see Fig. 7)
<b>C</b>	Cavity slab (see Fig. 6)	C <sub>I</sub> , C <sub>II</sub> ( see Fig. 8)

Figure 7. Plans indicating test partitions. a) Ground floor (A<sub>I</sub>, A<sub>II</sub>), b) First floor (A<sub>III</sub>, B<sub>I</sub>, B<sub>II</sub>)Figure 8. Section A-A' indicating test partitions (C<sub>I</sub>, C<sub>II</sub>)

Prediction of the sound insulation performance of the test partitions, was based on the classical theory as shown below:

For partition Type A [16]:

$$R = 20 \log(mf) - 48, \text{ dB} \quad (1)$$

$R$ : Sound Reduction Index dB,  $m$ : Mass  $\text{Kg/m}^2$ ,  
 $f$ : frequ. Hz

For partition Type B [16]:

$$R_c = 10 \log (1/T_{av}) , \text{ dB} \quad (2)$$

$R_c$ : Sound Reduction Index of composite wall, dB,  
 $T_{av}$ : Sound Reduction Coefficient of a composite partition (see Eq. 3)

$$T_{av} = (T_1 S_1 + T_2 S_2 + \dots) / (S_1 + S_2 + \dots) \quad (3)$$

$T_1, T_2$ : Sound Reduction Coefficient respectively of the elements 1,2, etc. (see Eq.4)

$S_1, S_2$ : Surface area respectively of the elements 1,2, etc.

$$R = 10 \log (1/T), \text{ dB} \quad (4)$$

For notation see Eq.1,3 above.

In predicting sound insulation for partitions of

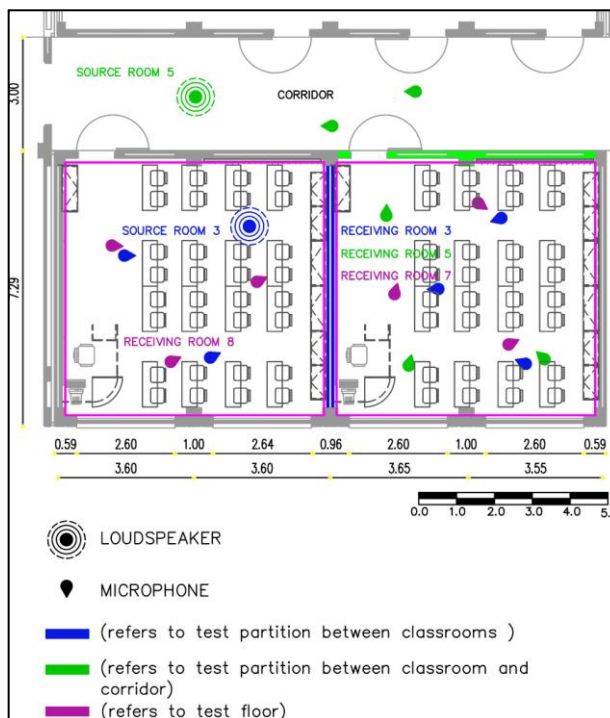


Figure 9. Typical measuring layout.

Type A the 1.0 cm cavity width was ignored as relatively insignificant.

The predicted sound insulation of partitions of Type A, was then used as a basis for the prediction of insulation for composite partitions of Type B. The sound insulation of the door and window involved, was taken respectively from the literature and it is shown in Table III.

For cavity partitions of Type C the sound insulation was predicted as follows [16]:

$$R = R_1 + R_2 - 20 \log (k/fd), \text{ dB} \quad (5)$$

$R$ : Sound Reduction Index dB,  $R_1$ : Sound Reduction Index of layer 1 dB,  $R_2$ : Sound Reduction Index of layer 2 dB,  $k$ :  $c/2\pi$  m/s,  $d$ : cavity thickness m,  $f$ : frequ. Hz,  $c$ : speed of sound in air = 340 m/s ( $17^\circ\text{C}$ )

Predicted results are shown in Table IV and Fig.10.

For each partition type tested, the adequacy of the measured sound insulation was evaluated (Table IV).

Table III. Sound Reduction Index (R) of door [17] and window [18] openings.

1/3 oct. band (Hz)	Sound Reduction Index -R, (dB)	
	Hollow core door	Closed, double window
100	3	21
125	5	24
160	7	29
200	9	22
250	11	26
315	13	23
400	15	29
500	17	33
630	19	33
800	21	34
1000	23	35
1250	25	35
1600	27	36
2000	29	37
2500	31	36
3150	33	34

In order to do this, a strict noise criterion value NR30 dB was adopted for the present classrooms in quiet suburb [17]. Also, in the predictions the teacher's voice from adjacent classroom (Table V), that was penetrating in the receiving room, was compared with a sound level lower than the criterion value by 5 dB, at all frequ. bands (Table VI). In this way the combined level of intruding noises in the receiving room is likely to not exceed the criterion value.

## 5. Results

Results are shown in Tables IV and VI and in Figure 10.

Table IV. Measured Sound Reduction Index.

Test Partitions		Weighted Sound Reduction Index (dB)			
Type	Sample	$R'_w$	$(R'_w + C)$	$R'_w$ (mean)	$R_w$ (theoretical prediction)
A	A <sub>I</sub>	48	48	48	61
	A <sub>II</sub>	47	46		
	A <sub>III</sub>	48	47		
B	B <sub>I</sub>	24	23	24	31
	B <sub>II</sub>	24	24		
C	C <sub>I</sub>	55	54	53	73
	C <sub>II</sub>	51	49		

Table V. Teacher's-voice Sound Pressure Level (SPL) at 1.00 m from source. *It is assumed to be equal to actor's-voice Sound Pressure Level at same distance from source.* [19]

	Oct. Bands (Hz)					
	125	250	500	1000	2000	4000
SPL	64	68	71	67	60	55

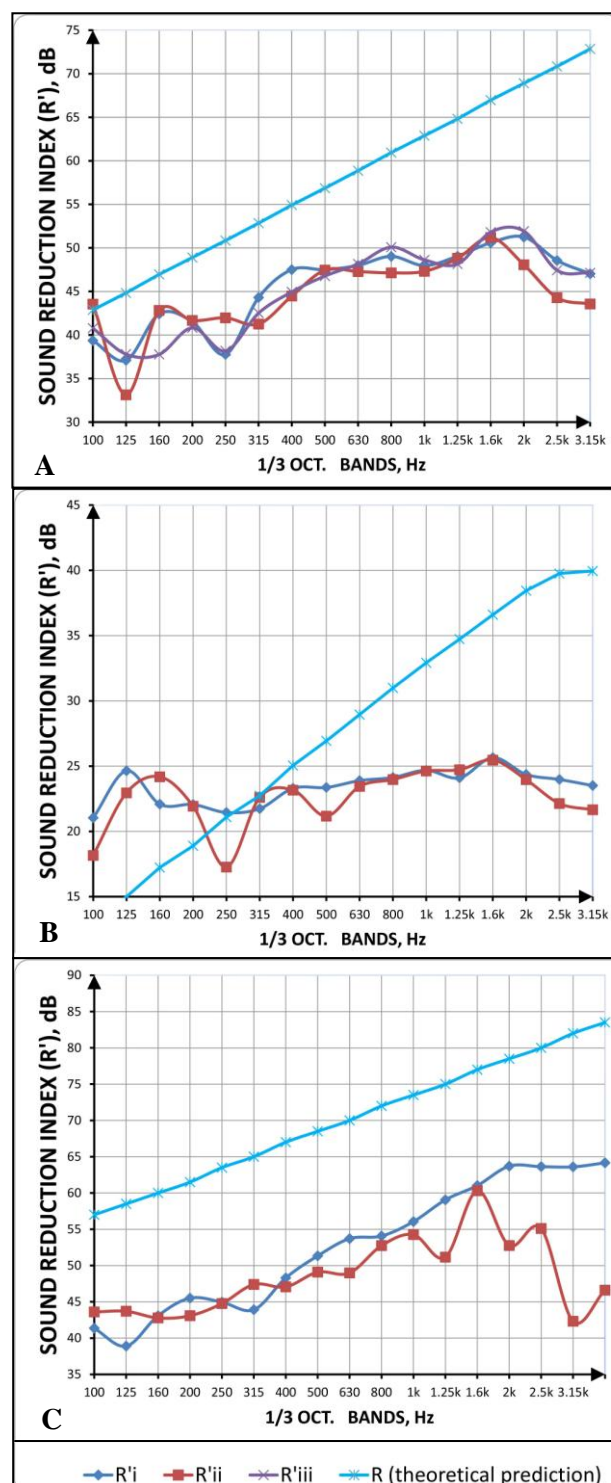


Figure 10. Measured Sound Reduction Index of partition Type A, B and C respectively (Table II).

Table VI. Predicted Sound Pressure Level of teacher's voice penetrating in the receiving room (SPLr)

Test Partitions		SPLr, (dB)					
Type	Sample	Oct. Bands, (Hz)					
		125	250	500	1000	2000	4000
<b>A</b>	A <sub>i</sub>	19	21	19	14	5	0
	A <sub>ii</sub>	17	21	20	14	7	5
	A <sub>iii</sub>	20	22	19	13	4	0
<b>B</b>	B <sub>i</sub>	36	41*	43*	38*	31*	25*
	B <sub>ii</sub>	36	42*	44*	38*	31*	27*
<b>C</b>	C <sub>i</sub>	17	18	15	5	0	0
	C <sub>ii</sub>	15	18	18	9	0	5
Note: * Values which do not satisfy the criterion are denoted in red.							

## 6. Discussion

For partitions of *Type A* (Table II) an average weighted sound reduction index for the test samples amounts to 48 dB (Table IV); this falls short by 13 dB compared to theoretical prediction (Fig. 10). The latter admittedly, is based solely on the mass law, and assumes no flanking transmission; by contrast measured performance involves also phenomena such as partition resonances, wave coincidence effect etc., which may impair the expected theoretical performance. Even so the measured sound insulation was found to satisfy the criterion value in the receiving classroom (Table VI). Based on the above findings, it can be inferred that flanking transmission between classrooms (Fig.3) is relatively insignificant for the given room function. Also, it is demonstrated that the concrete layers of the cavity partition between classrooms (Fig.5), are adequately heavy for the targeted sound insulation.

Regarding partition of *Type B* (Table II), an average weighted sound reduction index amounts

to 24 dB (Table IV). The latter is considerably shorter compared with the theoretical prediction. Apparently, the composite nature of this partition, allows for noise transmission through the poorly insulated door and window openings attached to this (Fig.3). Obviously, the criterion value in the receiving room i.e. in classroom, is not satisfied even for moderate noise levels operating in the corridor (Table VI). It is suggested that the sound insulation of the door and window openings are improved; for instance the hollow door leaf could be superseded by a solid leaf.

Regarding the slab of superimposed classrooms (*Type-C* partition, Table II), an average weighted sound reduction index amounts to 53 dB (Table IV). This, compared with theoretical prediction (Fig. 10, case C) falls short by 20 dB. Even so the measured sound insulation was found to satisfy the criterion value in the receiving classroom (Table VI). Based on the above findings, it can be inferred that flanking noise transmission between superimposed classrooms is relatively insignificant. Also, the surface weight and the relatively wide air gap of the cavity slab (Fig.6), are shown to contribute to satisfactory sound insulation. The impact sound insulation of the test slabs is not investigated, since this type of insulation is independent of any flanking noise transmission through such joints.

For each partition-type tested, repeatability of measured results between partitions confirms their reliability (Table IV).

Furthermore, the introduction of sound absorption in classrooms, such as it happens, for instance in the occupied classroom, could further improve the sound insulation performance of the test partitions. This can also control the state of class-room acoustic conditions.

## 7. Conclusions

For the three types of partitions tested, it has been demonstrated that there is relatively insignificant flanking transmission at the joints between prefabricated concrete elements, for the given room function. This is thanks to meticulous sealing at joints. It is also demonstrated the adequacy of surface weight of the test dividing partitions (*Type A* and *C* respectively) in their

capacity as sound insulators. Last, in the case of cavity slab (partitions Type C) the considerable width of air cavity is shown to contribute to satisfactory sound insulation performance. Nevertheless, the poor sound insulation of composite partition between classroom and corridor (partition Type B), is considered to be at owing to the poorly insulated door and window openings involved. This could be improved for instance by superseding the hollow door leaf with a solid leaf, maintaining resilient seal around the frame of the openings, etc.

The above findings confirm by and large the satisfactory sound insulation performance of the test building, which is of prefabricated concrete of the cell Type. A subjective acoustic evaluation experiment, using pupils and teachers in the test classrooms, could confirm further the validity of present findings.

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