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Lightweight ventilated facade prototype: acoustic performance evaluation when the ventilation surface of the air chamber varies

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1. INTRODUCTION

Lightweight ventilated facades potentially improve buildings protection against noise pollution from outside. However, in this system the air cavity is almost totally open, fully ventilated and not very wide. Therefore, its contribution to acoustics has not been considered in building projects to date.

The question that orients this contribution is: How much is the outside noise protection with the standard configuration on lightweight ventilated facade and how can improve:

- If changes the external wall cladding standard configuration.
- If the air layer becomes to an air cavity varying the open ventilation from total to zero.

Lightweight ventilated facade systems are increasingly common as they are light easy to apply and have the above advantages in new and renovated buildings.

- They improve the protection from direct sun radiation due to the double envelope and the ventilated air cavity that refrigerates the heat.

- They reduce in the transfer of humidity from rain to the building as the ventilated air cavity dissipates excessive humidity.

Situation of Current regulations

In Spain there are no specific regulations for lightweight ventilated facade systems. Consequently, the Codigo Técnico de la Edificación [1] needs to be applied. This regulation is comprised of different baseline documents (DB) depending on the area to be regulated. In the DB-HS [2] the air cavity`s characteristics are defined as well as its thickness and the ventilation surfaces. The DB-HE [3] defines when to consider the use of an air ventilated cavity.

In others baseline documents (DB) the lightweight ventilated facade system is only partially defined and neither limit values nor evaluation criteria are determined. For example, in the DB-HR [4] the values of requirements and verification are established for entire façade but the evaluation criteria only apply to the inner wall of the system which is the only element that requires compliance. Neither the air cavity nor the external cladding is including as an element that improves the acoustic performance of the façade. Therefore, the DAU documents [5] that are provided by lightweight ventilated facade manufacturers only take into account the contribution of the inner wall in values for protection against noise.

In the European Union the European Technical Approvals Guidelines (ETAG) are taken as a benchmark these documents contain the requirements for the use to the external claddings in lightweight facades. The document DITE 034- Kits for External Wall Claddings [6] (DRAFT ETAGE Nº12) is used to approve lightweight systems. It defines the thickness of the ventilated air cavity and the minimum values of ventilation surfaces in the air cavity. However this document does not establish any criteria for assessing the contribution to acoustic protection.

According to some authors [7] when an external wall cladding with an intermediate ventilated air cavity is added to a conventional façade, the acoustic insulation of the resulting façade unit could increase almost to 7 dBA. However the real improvement with this façade system probably fluctuates between 3 and 4 dBA in the middle-high frequency range (1000Hz).

Aims of the research

This research focuses on an “in situ” evaluation of a high performance lightweight ventilated façade system to determine its potential contribution to the acoustic insulation of existing facades. We designed and built some prototypes based on the lightweight ventilated façade system to parametrize its acoustic performance.

It known that a non-ventilated air cavity in a double wall increases the acoustic insulation of the unit. This contribution to acoustic insulation increases in the middle-high frequency range if an acoustic absorbent material is placed inside the cavity. To further reduce low frequencies of noise (that are prevalent in external noise in cities) the superficial mass of the external wall cladding needs to be increased.

This is not an option in lightweight systems. However the thickness of the air cavity can be increased, which also improves results in the low frequency range. Nevertheless that it works to contribute on the good results at low frequencies rank. Although there are not references, there are no studies on the possibility of establishing a graded level of ventilation in the air cavity and its influence on noise protection.

2. FIELD TRIALS

We designed and built 3 models of lightweight ventilated façade using different configurations of external wall claddings and the same thickness in the air cavity in each case. We established a graded level of ventilation in each model, by varying the opening of the ventilation surface of the air cavity (5 positions). These 3 models were installed in a real façade. Subsequently the respective acoustic trials were carried out to assess the protection level. The trials were performed according to the ISO regulations.

Trial conditions

The trials were carried out on a section of wall with no openings in the posterior façade (north facing) of the *Escola Tècnica Superior d`Arquitectura del Vallès* (ETSAV) building *Universitat Politècnica de Catalunya* (UPC). The trial area was 9,60m wide x 6,00m high and corresponds to the first floor of the building inside the space is a student rest room. The total surface in the room is132,87 m^2 and the volume is 660,8 m^3.

The façade is a 30 cm thick double brick. The wall is formed of two layers made of different kinds of brick 9cm and 14cm separated by an air cavity 7cm approx. As the trial area was a section of the façade of a real building it had some irregularities to consider:

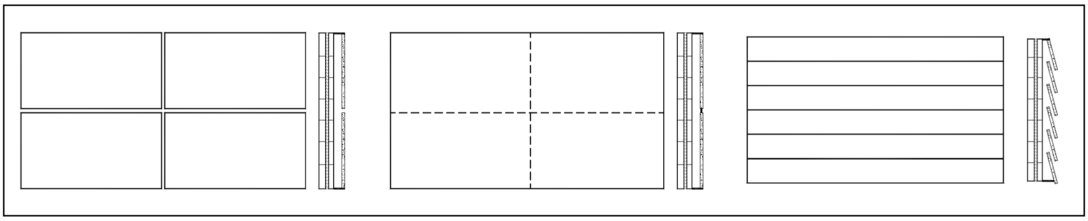
- In the middle of the study area of the façade there is an expansion joint between two stages in the construction of the building.
- The inner ceiling of the room contains skylights made of extruded polycarbonate.
- The lateral enclosures of the room are partitions made of aluminium frames and glass.
- The floor is a reinforced concrete base of 20cm thickness with the overall rate of noise reduction R highest than the original façade wall base of trial.

Previous adaptation of the room and in the wall base façade

The room was adapted to minimize the influence of the irregularities described above. The skylights were protected from the inside with 40mm semi-rigid rock wool panels and from the outside with an insulating textile material made of asphalt and rock wool that was 20mm thick. The expansion joint was protected from the inside of the room with the same material used in the construction of the prototypes installed in the façade: a rock wool textile of 40mm.

Definition of the prototype models

Fa, lightweight external cladding made of “Aquapanel Knauf” standard glass reinforced concrete (GRC) panels, with sealed joints between the panels.
Fb, lightweight external cladding made of “Aquapanel Knauf” standard glass reinforced concrete (GRC) panels, with open joints between the panels.
Fd, lightweight external cladding louvers made of “Aquapanel Knauf” standard glass reinforced concrete (RGC). The louvers are overlap with the same distance between each one.

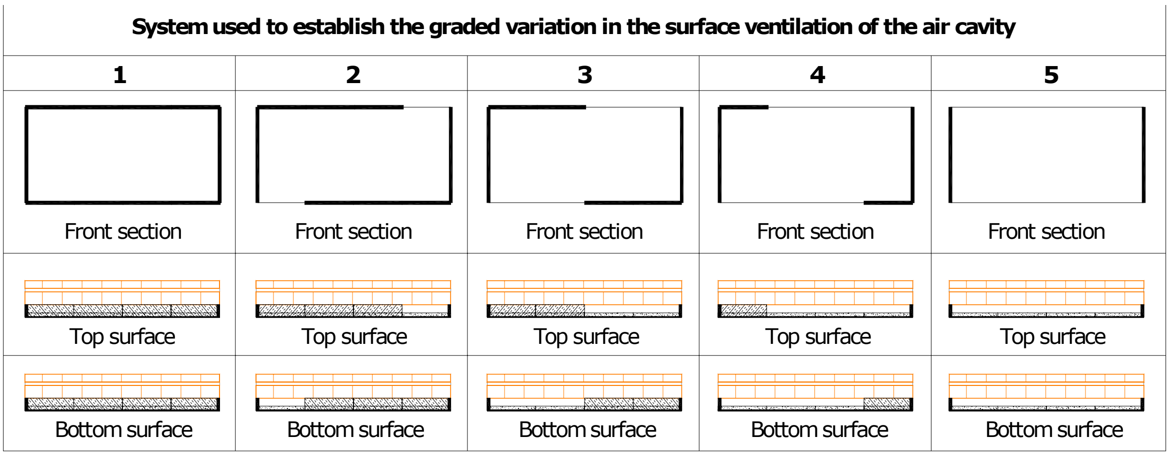


Fb Fa Fd

The “Aquapanel Knauf” RGC panels (2,40mx1,20mx12,5mm) were screwed onto a substructure of 50x50mm sections made of galvanized steel fixed at the base wall of the façade by 78mm brackets. The model Fd model had a slightly different substructure to provide the slope needed for the 50mm overlap in the louvers with a 10mm distance between each one. The air cavity in the models was 100mm wide and obtained by joining two sections of 50x50mm galvanized steel. Both vertical perimeters of the air cavity in the prototype models were totally closed. A 40mm mineral wool layer was installed inside the air cavity and attached to the base wall.

Variation in the opening of the air cavity

The grades variation in the opening of the air cavity`s ventilation surface was established by segmenting the upper and lower horizontal perimeter of the prototype model into 5 areas. This was achieved using part of panels of Aquapanel GRC which were successively removed during the acoustic trials as shown in the diagram below.



1(0% ventilated-closed) **2**(25% ventilated) **3**(50% ventilated) **4**(75% ventilated) **5**(100% totally- ventilated)

Trial procedure

The acoustic trials were carried out in accordance with the current standards for acoustic measurements [8] UNE EN ISO 140-5, [9] UNE EN 1235-3, [10] UNE EN ISO 717-1 and taking into account CTE DB-HR and the technical and human support to from the Laboratori d`Enginyeria Acústica I Mecànica de Terrassa *Universitat Politècnica de Catalunya* (LEAM-UPC).

Schedule and equipment used in the in situ trials.

Week 1	Previous adaptation, installation of the shared substructure on the existenting façade, assembly of the **Fd** prototype and acoustic trials.
Week 2	Dismantling the **Fd** prototype, assembly of the **Fb** prototype and acoustic trials.
Week 3	Assembly of the **Fa** prototype (seal the joints) and acoustic trials.

Week 4	Dismantling of the **Fa** prototype and the substructure and recovery of the original façade **FI** (without the prototypes) followed by acoustic trials.
Measuring equipment	-Exterior sound source pink noise from a JBL model EON 15G2 loud speaker. -The interior **LTS** was measured by an SLM SC310 CESVA type 1.0,1dB -The exterior **LTS** was measured by a similar SLM using a mobile microphone.

The acoustic measurements were made in third octave frequency bands, starting in the 20Hz. range However for the subsequent analysis of the results, the lowest evaluation frequency was taken as100Hz.

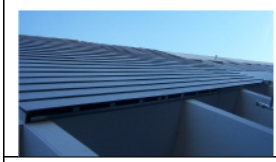
In some of the trials, there were some accidental errors in the measurements, which were rapidly detected as these results were not consistent (values highlighted in grey the results table). In the Fb prototype, the erroneous values have been replaced by extrapolated values, to maintain an overview of the whole trial. In the interpretation of the results, it should be noted that the trial only involved a section of the façade. Consequently, the sound insulation inside the designated room is not complete and the room does not have the ideal conditions of a laboratory. However, the conditions are closer to a real situation.

The time required to successively install, dismantle and carry out acoustic trials for each one of the prototype models in real circumstances probably led to a variation in the surroundings conditions (the weather, the time of the acoustic measurements, the activity in the rest of the building, among others) that could have affected the comparison process. Evidently these disadvantages could be eliminated in a laboratory, but the results obtained by in situ measurements will be closer to the reality of a renovated building for example.
According to UNE EN 12354-3:2000 the results shown in the table were obtained using the normalized difference in levels equation (1) measured as established in UNE En 140-5:1999 for in situ measurements 2m in front of the façade. These results are not comparable with laboratory measurements.

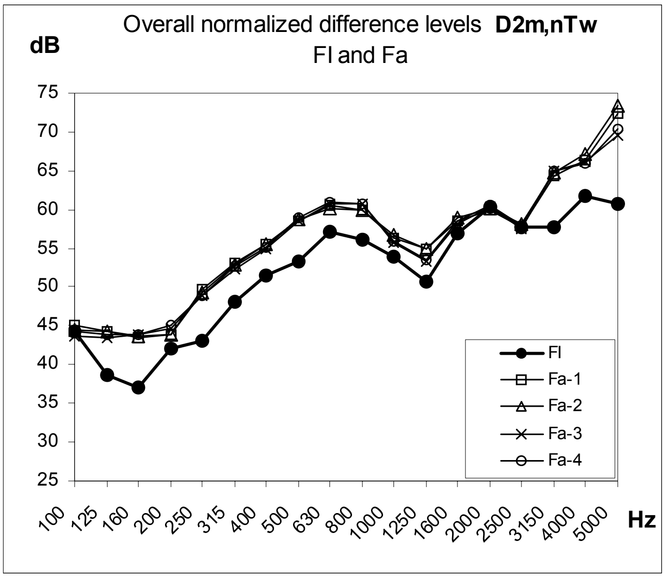
$$D_{2m,nT} = R' + \Delta L_{fs} + 10\lg\frac{V}{6T_0 S}\ \text{dB} \qquad (1)$$

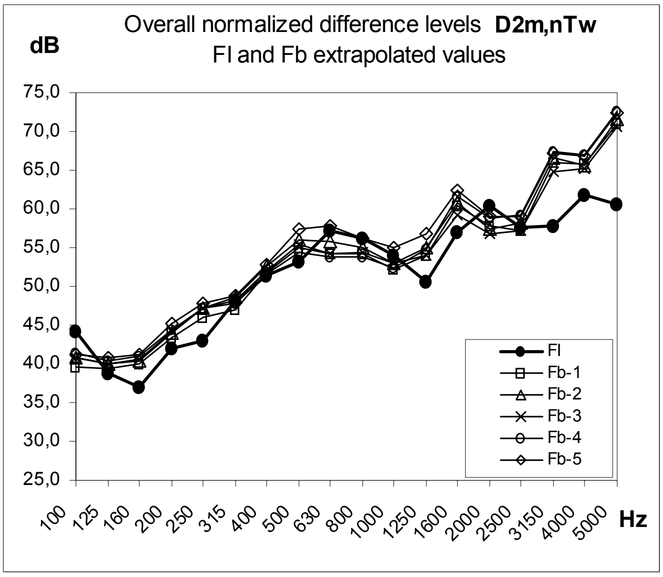
3 SUMMARY OF RESULT

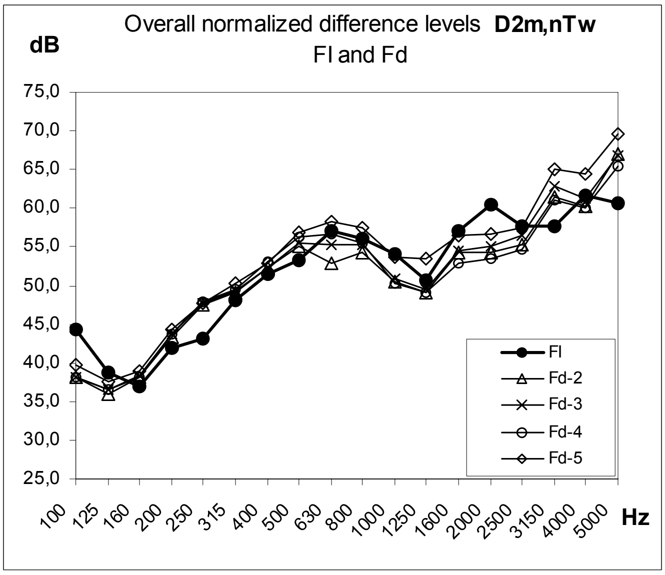
The following table shows the overall results obtained with ***D*2m,nTw** using the different prototype models after in situ acoustic evaluation of the grades variation in the opening of the air cavity's ventilation surface.

	**Fa prototype model (panels with sealed joints)**					**FI**
	Fa-1 0% ventilated	**Fa-2** 25% ventilated	**Fa-3** 50% ventilated	**Fa-4** 75% ventilated	**Fa-5** 100% ventilated	Original façade base wall
***D*2m,nTw**	58,5	58,7	58,5	59,0	36,0	53,3
	**Fb prototype model (panels with open joints)**					**FI**
	Fb-1 0% ventilated	**Fb-2** 25% ventilated	**Fb-3** 50% ventilated	**Fb-4** 75% ventilated	**Fb-5** 100% ventilated	Original façade base wall
***D*2m,nTw** (Extrapolated values)	55,0	56,1	55,4	54,3	57,4	53,3
	**Fd prototype model (louvers with and overlap between them)**					**FI**
	Fd-1 0% ventilated	**Fd-2** 25% ventilated	**Fd-3** 50% ventilated	**Fd-4** **75%** ventilated	**Fd-5** 100% ventilated	Original façade base wall
***D*2m,nTw**	39,0	55,0	55,4	56,2	56,8	53,3

The next diagrams show some of the analysis frequency by frequency of the different systems compare to FI.







CONCLUSIONS

The building and the room chosen for in the trial give an idea of the singular features that could complicated the evaluation of sound insulation in the prototype models. However the value obtained for the overall rate of noise reduction R`$_{45^\circ}$ in the configuration FI 47,4dB R`$_{45^\circ A}$ (original façade base wall with not prototypes) is not far from the normal values tabulated in the reference literature for a wall with similar characteristics (44dB R$_A$). The base floor has an overall rate of noise reduction corresponding to a reinforced concrete base of20cm between 56 to 60dB R$_A$ [11] (*Catálogo de elementos constructivos CTE*), this value limits the observation of the improvement obtained by the prototypes installed.

As shown in the table above, there was a general improvement of around 5dB in the overall normalized difference in levels ***D*2m,nTw** when the Fa prototype model was used compared to the original façade FI. An improvement of around 3dB (extrapolated value) was found for the Fb prototype model and 2dB for the Fd prototype model with louvers when the air cavity was totally closed (without ventilation).

The five graded variations in the opening of the air cavity's ventilation surface in the different prototypes did not seem to notably affect the overall normalized difference in levels. There are several possible reasons for this: 1) the effective air layer was small, due to the thickness of the air cavity (and was made even smaller by the mineral wool), 2) the influence of upper and lower ventilation surface in the prototypes as well as the system used to open the air cavity in comparison with the size of the entire façade and the volume of the room and 3) the perpendicular situation of the ventilation surface compared to the direction of the exterior sound waves.

In the frequency by frequency analysis of the results the trend of better noise reduction results was more pronounced in the high frequency range. Noise in this range can easily be reduced using existing solutions. In addition, there was an improvement in the lowest frequency range. This improvement was not as marked possibly due to the narrow thickness of the air cavity.

In general, the results were positive and encouraging given the real in situ circumstances in which this study was carried out.

5. FUTURE RESEARCH

This study provides an approach to quantifying improvements in the acoustic performance of the lightweight ventilated façade systems with air cavities. It could form the basis of future research in laboratory or with software simulations. Future research in this area should focus on:

- The thickness of the air cavity, to improve the results for the lowest frequency range in particular.

- Improvement in the boundaries of the prototypes especially where they meet windows. The system for varying the ventilation in the air cavity should be implemented in these boundaries.

6. REFERENCES

[1] Architecture and Housing Policy Directorate General of the Ministry for Housing with the cooperation of the Eduardo Torroja Construction Sciences Institute (IETcc) which belongs to the Higher Council for Scientific Research (CSIC)- **CTE** Código técnico de la edificación (Spanish Technical Building Code), Spain 2006.
[2] CTE Código técnico de la edificación (Spanish Technical Building Code)-**DB-HS** Documento Básico de ahorro de energía (Baseline document salubrity), Spain last actualization October 2009.
[3] CTE Código técnico de la edificación (Spanish Technical Building Code)-**DB-HE** Documento Básico de ahorro de energía (Baseline document saving energy), Spain last actualization April 2009.
[4] CTE Código técnico de la edificación (Spanish Technical Building Code)-**DB-HR** Documento Básico de Protección Frente al Ruido (Baseline document protection against noise), Spain last actualization September 2009.
[5] ITec Institut de tecnología de la construcció de Catalunya- **DAU** Documentos de Adecuación al Uso documents of adequate to use. Evaluates the technical suitability of products and innovative building systems, forwhich there are no normative standards consolidated.
[6] ETA (European Technical Approval)- DRAFT ETAGE Nº12 **DITE 034**- Kits for External Wall Claddings part of the *Technical Approvals Guidelines* (ETAG), January 2006.
[7] CSTB Centre Scientifique et Technique du Bâtiment- Le mur manteu: synthèse des règles et codes. Etudes et recherches, Cahiers du (Livraison 349, Cahier 2719), France May 1994.
[8] ISO- UNE EN ISO 140-5 Measurement of sound insulation in buildings and of building elements. Part 5: Field measurements of airborn sound insulation of façade elements and facades, 1998.
[9] ISO- UNE EN 1235-3 Building acoustics. Estimation of acoustic performance of buildings from the performance of elements. Part 3: Airborne sound insulation against outdoor sound, 2000.
[10] ISO**-** UNE EN ISO 717-1 Rating of sound insulation in buildings ando f building elements. Part 1: Airborne sound insulation, 1996.
[11] CTE Código técnico de la edificación (Spanish Technical Building Code)-Catálogo de elementos constructivos (Catalog of building elements) written by CSIC Instituto Eduardo Torroja de ciencias de la construcción, Spain 2010.