ACOUSTIC PERFORMANCE TEST ASSESSMENT ON SOUND GENERATED BY RAINFALL ON MULTILAYER-ETFE-CUSHION SYSTEMS

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Key words: ETFE cushion, Acoustic Performance, Rainfall.

Summary. Ethylene-tetra-fluor-ethylene (ETFE) membrane structure presents itself as an innovative construction element, taking advantage of its flexibility, lightweight, transparency and thermal insulation properties. However, for large enclosed areas, concerns exist related to the sound insulation characteristic of the system, especially related to the internal noise levels generated during rainfall conditions. Therefore, aiming to both assess the effect of rain noise on these structural elements, as well as generating a clear picture to this condition to designers and clients, Taiyo Europe promoted a measurement campaign on a predefined set of pneumatic ETFE roof elements. The set of pneumatic cushions investigated was produced from the same 250-micron thick ETFE foil. The number of layers, number of air chambers and the level of the pressure inside the cushion was variable, following a carefully predefined test plan. The elements were tested with and without an additional rain suppressor fabric mesh on top of the specimen. The tested elements were installed on a special outdoor structure designed and built for this purpose. This work will describe the tests performed, as well as an assessment of the results achieved and their impact on the design of enclosed buildings cladded with ETFE pneumatic structures.

1 INTRODUCTION

As an innovative construction element, it has already been extensively discussed on the literature the benefits of the multilayer-ETFE-cushion systems in comparison to other roof systems, including its aesthetic value, design flexibility, durability and lightweight. However, due to the small mass per unit area of these foil system, they mostly present a lower sound insulation than solid building materials and little reliable acoustical data (on the system) is available on the literature [1].

Therefore, the current document presents the outcomes of a measurement campaign on a set of multilayer-ETFE cushions, supplied and installed by Taiyo Europe GmbH, aiming to assess the rain noise effect on these systems.

These tests were performed by the Textiles Hub Laboratory at Politecnico di Milano from July 18th to 22nd, 2016, at their own premises (31 Ponzio St., Milan, Italy).

2 TEST ARRENGEMENT AND PROCEDURE

The tested cushion samples were manufactured with the same geometry (3,2m x 3,4m) and using the same 250 micron clear ETFE foil. However, the number of layers, number of air chambers and inner pressure within the chambers were variable (**Table 1**).

Moreover, samples with and without the installation of an outer fabric mesh rain suppressor were also assessed. Covering a film with a mesh aims to reduce the rain noise from ETFE system, once the rain accumulates inside the mesh and forms a layer of water, which will weaken the strikes of the rain drop and also damps the vibration of the roof [1].

Table 1: List of Tests Performed

Test Code	Description of the tested specimen				
	Number of layers	Inner Chamber pressure		Rain type	Rain supressor
		Middle [Pa]	Outer [Pa]		
L4_P300_HR_O	4	400	300	Heavy	
L4_P600_HR_O	4	700	600	Heavy	
L4_P900_HR_O	4	1000	900	Heavy	
L3_P300_HR_O	3	400	300	Heavy	
L3_P300_HR_R	3	400	300	Heavy	Yes
L3_P300_IR_O	3	400	300	Intense	
L3_P300_IR_R	3	400	300	Intense	Yes
L3_P600_HR_O	3	700	600	Heavy	
L3_P900_HR_O	3	1000	900	Heavy	
L2_P300_HR_O	2	-	300	Heavy	
L2_P600_HR_O	2	-	600	Heavy	
L2_P900_HR_O	2	-	900	Heavy	

The following standards were considered on performing these test:

- International Standards Organization, “Acoustics - Measurement of sound insulation in buildings and of building elements - Part 18: Laboratory measurement of sound generated by rainfall on building elements (ISO 140-18:2006)”. International Standard DIN EN ISO 140-18:2007-02.

- International Standards Organization, “Acoustics - Laboratory measurement of sound insulation of building elements - Part 1: Application rules for specific products”. International Standard DIN EN ISO 10140-1:2016-12.
- International Standards Organization, “Acoustics – Measurement of sound insulation in buildings and of building elements using sound intensity – Part 1: Laboratory measurements”. International Standard ISO 15186-1, 2000-03.

2.1 Test Hut

A special insulated outdoor hut was built at POLIMI labs, in order to arrange the ETFE system specimens to be tested. This hut is shaped as a 3,5m x4,5m box, with variable height (from 2,5m to 3,5m), in order to create an inclined roofing surface (roughly 20^{o}) as recommended by the followed standards. It was fabricated using steel structure and insulated lightweight drywalls (**Figure 1**).

The whole inside surface was treated with sound-proof materials, using both mineral wool, polyester non-woven mattresses and melamine foam modules, aiming to reducing the internal reverberation components and allowing a better use of intensimetry method.

Figure 1 (left): External View of the Test Hut;
Figure 2 (right): Detail of the Steel Tank Perforated Base Used for Simulating Intense and Heavy Rain Scenarios.

2.2 Apparatus for rainfall simulation

For artificial raindrop production, a movable tank with a perforated base (area of 1,60m^{2}) was installed over the hut, following the specifications defined on DIN EN ISO 140-18:2007-02 (Table A.1 of Annex A). This allowed the simulation of two different conditions: INTENSE and HEAVY rain (**Figure 2**).

The heavy rain scenario was achieved by producing a rainfall rate of 40 mm/h from the base suspended 3,5m over the test specimen. The intense rain scenario was achieved by producing a rainfall rate of 14 mm/h from the base suspended 1m over the test specimen (see **Figure 3**).

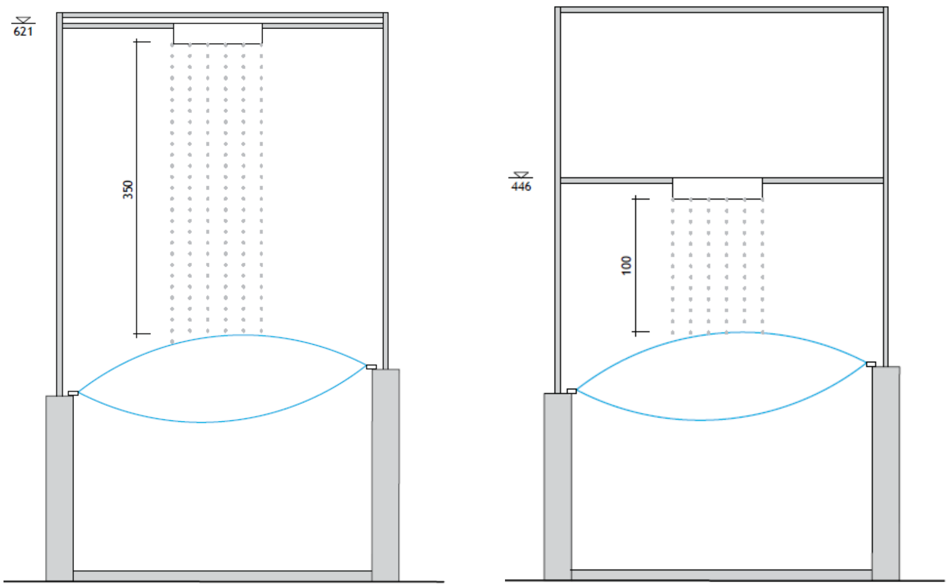


Figure 3: Schematic Section of The Test Unit, With the Configuration for Heavy (Left) and Intense (Right) Rain.

2.3 Rainfall Measurement

The rainfall measurement area was arranged in a grid subdivided in 24 (6x4) sub-areas. A microphone was positioned at the center of each of those 24 sub-areas.

The time of measurement was of at least 20 seconds of each 24 points, from which the spectra of results were built on a frequency range corresponding to one-third octave, from 100Hz to over 5000Hz.

The measurement frequency range was organized in ranges of one-third octave and one octave (from 100Hz to 5000Hz). Sound intensity level was then calculated for each cushion configuration. Furthermore, the Global A-weighted sound intensity level was calculated by adding A-frequency weighting to the measured results of the whole ranges.

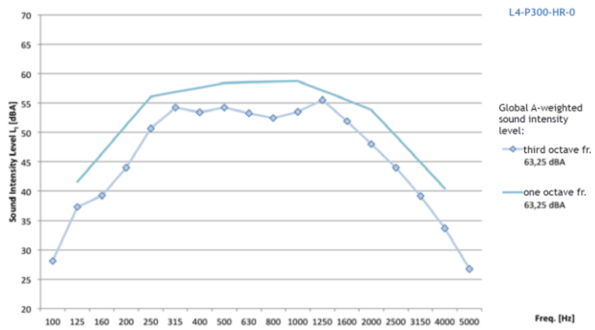
2.4 Possible interferences during the tests

In order to assess possible interferences during the tests, the surrounding acoustic level was measured to validate both the sound intensity and sound pressure measurements. The following sound sources were registered as the main components of the background sound level during the test campaign: blowing machine sound, water pump noise, anthropic noise and traffic noise.

The background sound was measured on every day of the test campaign. The result was always 10db lower than the registered measurements. Therefore all the tests results were not influenced by the background sound.

3 RESULTS

The following graphics present the result of the tests described on Table 1.



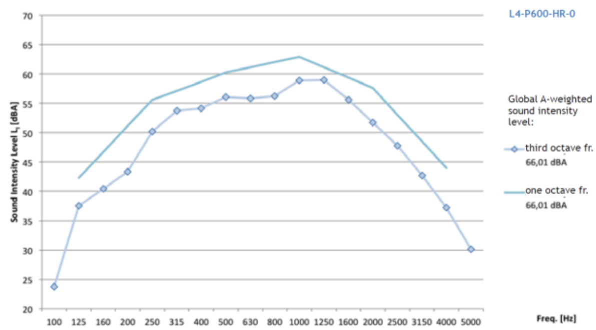


Figure 4 (left): Test Result L4_P300_HR_O; Figure 5 (right): Test Result L4_P600_HR_O.

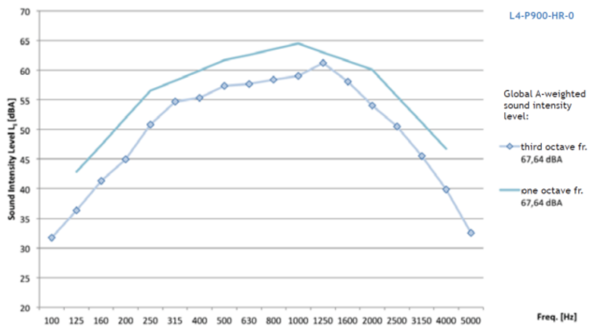
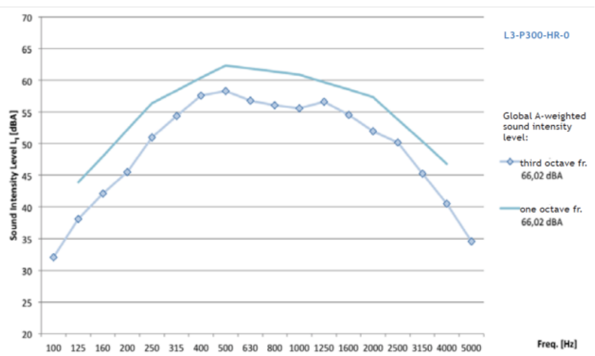


Figure 6: Test Result L4_P900_HR_O.



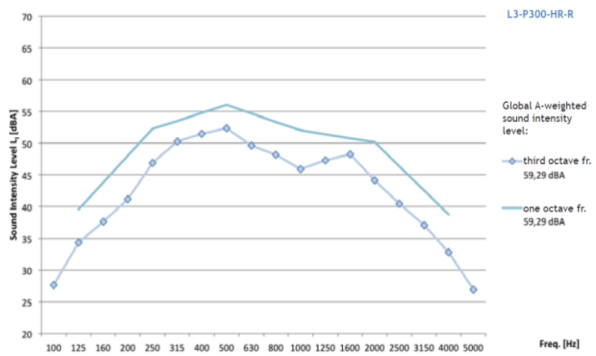
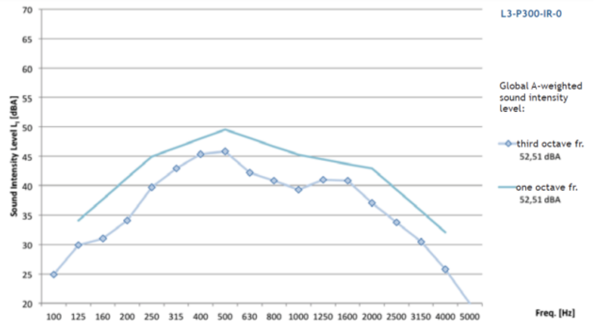


Figure 7 (left): Test Result L3_P300_HR_O; Figure 8 (right): Test Result L3_P300_HR_R.



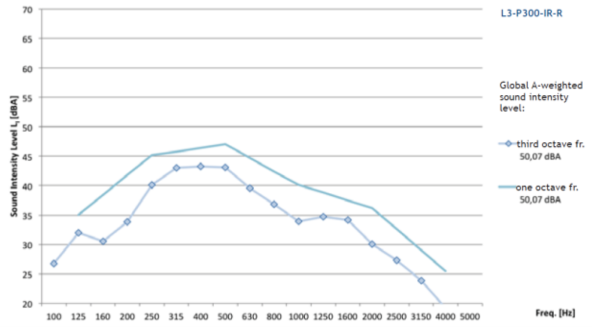
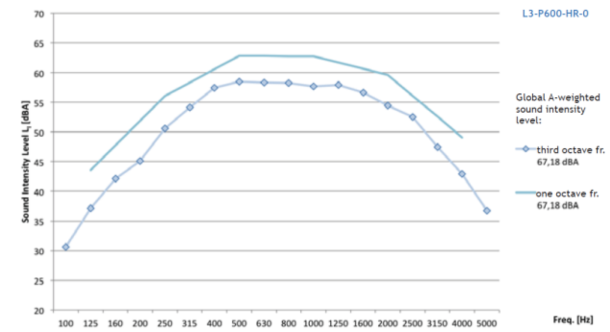


Figure 9 (left): Test Result L3_P300_IR_O; Figure 10 (right): Test Result L3_P300_IR_R.



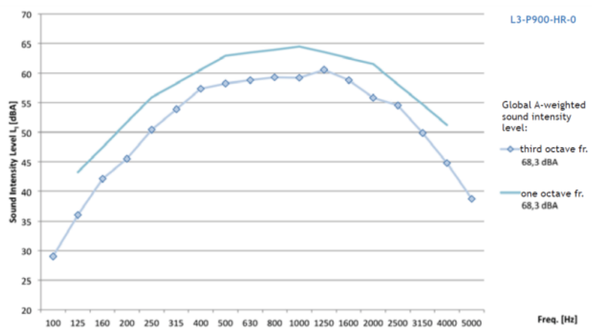
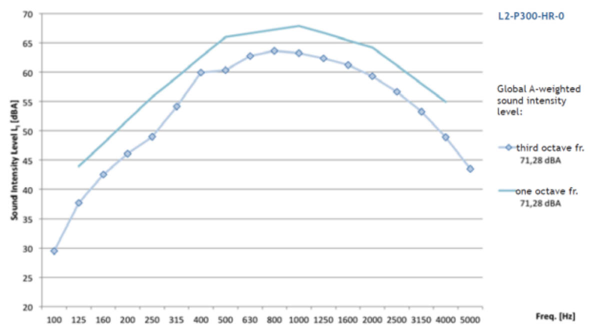


Figure 11 (left): Test Result L3_P600_HR_O; Figure 12 (right): Test Result L3_P900_HR_O.



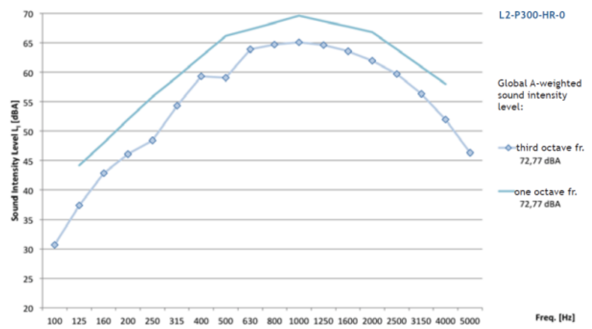


Figure 13 (left): Test Result L2_P300_HR_O; Figure 14 (right): Test Result L2_P600_HR_O.

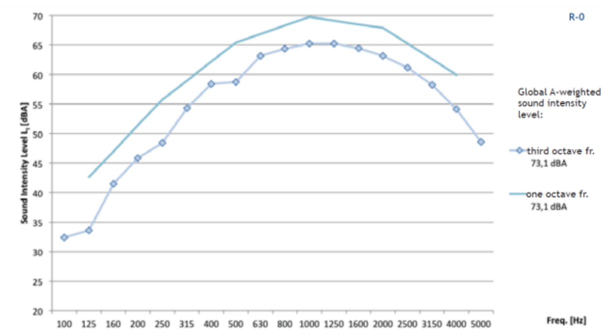


Figure 15: Test Result L2_P900_HR_O.

4 DISCUSSION

A comparative evaluation of the test results indicate (as expected) that the quantity of layers (and air chambers) affect the rain noise perceived under the ETFE cushion. The more layers the system have, the lower the rain noise levels under it.

Following a comparison between samples with the same configuration of the ETFE layers but with variation on the inner pressure, it is observable that the intensity of the rain noise increases following an increase of the internal air chamber pressure. However, in the range of the lower frequencies (under 1kHz) the different inner pressure levels seem not to affect the rain noise perception.

A comparison between samples with the same configuration of the ETFE layers, with and without adding an external rain suppressor layer show that the rain suppressor contributes more during an intense rain than a heavy rain. During the Intense Rain set-up, the maximum difference between the specimen's configuration with and without rain suppressor is 6,68 dB. During the Heavy Rain set-up, the maximum difference is 5,23 dB. Furthermore, the results show that the rain suppressor seems not to give a significant contribution for frequencies under 1kHz – region where we found the rain noise intensity peak.

5 CONCLUSIONS

This work presents an assessment of the noise derived from heavy and intense rain on multilayer-ETFE-cushion systems. It also brings a clear picture to this condition to researchers, designers and clients.

The generation of rain noise was experimentally investigated on a number of different ETFE cushions configurations. It concludes that the quantity of layers and the inner system pressure affects the rain noise.

It also indicates that the application of a rain suppressor fabric mesh over the system does not to give a significant contribution for frequencies under 1kHz – region where we found the rain noise intensity peak. Therefore, the decision for the application of this element should be assessed along with other project related specificities, such as: Additional implementation costs; visual obstruction (reducing the translucency of the system); and additional maintenance costs (once the mesh will accumulate airborne suspension, affecting not only its aesthetical appearance but also reducing the system's light transmittance).

REFERENCES

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[2] M. Toyoda, D. Takahashi, "Reduction of Rain Noise from Ethylene/TetrafluoroEthylene Membrane Structures", Vol. **74**, pp. 1309-1314, (2013)