



Preliminary evaluation of ventilation and acoustics insulation of partially open windows for the PRIN – METAWAVE project

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ABSTRACT

The PRIN-METAWAVE project aims at providing innovative solutions that might simultaneously satisfy different requirements. Windows have multiple roles in assuring a good façade performance: they must provide natural lighting, give good insulation against outdoor noise, provide ventilation when opened and mitigate overheating by use of special glasses, shades etc. These diverse functions are commonly considered disconnected in building design, so that strategies to control these different systems have been developed with entirely separated approaches.

This research project aims to overcome the above-mentioned disconnections in order to advance the technology readiness level of windows based on the acoustic metamaterial science to improve their noise control performance while assuring a good natural ventilation.

Preliminary measurements of natural ventilation of an on-site windows in the ITC-CNR real scale ZEB (Zero Energy Building) facility, will be performed alongside façade sound insulation measurements both with different window opening.

1. INTRODUCTION

The pressure for greater energy efficiency is pushing the building industry towards new performance standards that often involve other aspects that are important for the indoor environmental quality. Windows are the best example where all aspects come together; they have multiple roles in ensuring a good façade performance: they must provide natural lighting, good insulation from external noise, good thermal insulation in winter and ventilation when open to mitigate overheating in summer. These different functions are often considered unconnected in building design, so separate strategies have been

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developed to control these different systems individually [1]. This leads different designers to make different and incompatible assumptions about the conditions of indoor environmental quality: for example, the acoustic designer assumes that windows are closed to control the external noise, while the mechanical designer assumes that windows are open in summer for ventilation or to mitigate overheating. This can oblige the occupants to choose one function and exclude the other; obviously, neither choice is optimal for indoor comfort [2].

Optimizing both noise reduction and ventilation at the same time is a challenge in the sustainable design of innovative windows. An essential step towards the development of window solutions for an efficient building envelope is the complete understanding of the current state of the art, the most frequently used design criteria and the existing correlations between acoustic and ventilation performance [3].

Among the possible solutions, metamaterials offer new opportunities and customized solutions. The Construction Technologies Institute (CNR-ITC), the University of Bologna and the Politecnico of Bari are jointly developing a PRIN project entitled METAWAVE (New METAmaterial Window for simultaneous Acoustic, Ventilation and Energy performance) with the aim of using the principles of metamaterials applied to windows, to achieve the desired ventilation without energy consumption and, at the same time, maintain a good sound insulation. The present work takes stock of the progress of the project.

2. STRATEGIES FOR SOUND INSULATION AND VENTILATION OF WINDOWS

Natural ventilation is effective in reducing cooling loads in buildings [4], while improving thermal comfort [5] and saving energy by 10% to 30% [6]. Many existing studies do not consider that the ventilation rate changes with window type, opening area and opening degree [4, 7], resulting in the widespread practice of using a constant ventilation rate to predict energy in buildings, which may cause inaccurate results [4]. Therefore, continuous efforts have been made to explore the correlation between the effects of natural ventilation and window design [8].

As pointed out by Rubino et al. [3], Computational Fluid Dynamics (CFD) models have proven to be a valuable support tool for studying ventilation under controlled conditions. The calculation of natural ventilation air flow through windows is most frequently performed by considering discharge coefficients that take into account the air flow efficiency or, alternatively, the air flow resistance of the openings.

It is necessary to study the sound insulation of partially open windows in order to have a reference to verify the effectiveness of metamaterials applied to windows in these conditions, thus allowing natural ventilation but increasing sound insulation. Several works can be found in the literature but they are not very comparable [3]. In fact, the sound insulation properties of open or partially open windows are difficult to compare with each other, since different researchers refer to different parameters and use methodological approaches that do not comply with standard procedures (or comply with different national regulations), also making it difficult to separate the contribution of the window from that of the walls. Furthermore, all measurements relating to the façade, even with closed windows, are influenced by a high-frequency uncertainty that depends on the direction of the sound incident on the façade [9].

2.1. Ventilated metamaterials

The literature survey [3] shows that acoustic metamaterials (AMM) that can perform this dual function i.e. allow natural ventilation, while maintaining good acoustic insulation, can be divided into 4 main categories (fig.1):

- Individual resonator AMMs: characterized by systems that use individual resonators (single frequency);
- Stacked resonators AMMs: metamaterials that, while relying on a single resonant process, by stacking multiple devices, extend the frequency range in which the device is effective;

- Broad-band gradient-array AMMs: systems that can significantly extend the frequency range in which they effectively reduce sound transmission, thanks to optimized combinations of several simple resonators that have a multi-peak behavior;
- Other (hybrid) approaches: AMMs based on physical principles not included in the previous groups or that use hybrid approaches.

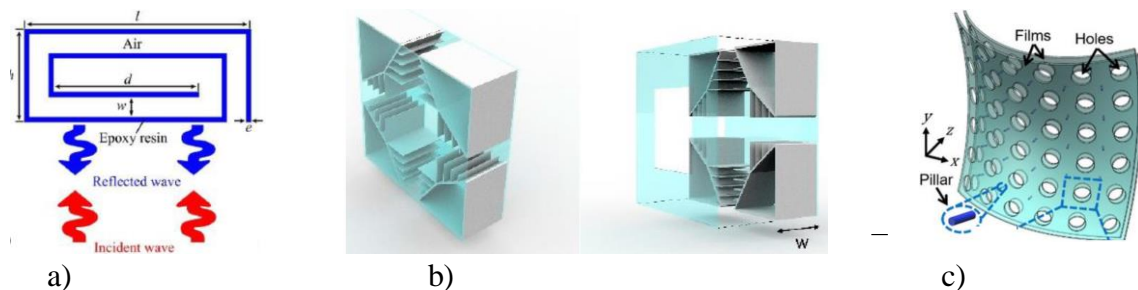


Figure 1 – a) Individual resonator AMM coiled resonator [10] (CC BY 4.0 license) b) Broad-band gradient AMM [11] (CC BY license) c) hybrid approach AMM [12] (CC BY license)

To compare the acoustic performance of the selected solutions in [3], the Transmission Loss (TL) as a function of frequency was considered. Since most of the papers refer to a desirable TL of 10 dB ($TL \geq 10$ dB), reasonably derived from the human psychoacoustic response [13], and to the average improvement achievable using “conventional” window solutions, this threshold was considered as the one to be reached to achieve good sound insulation with partially opened windows.

Rubino et al. [3] have highlighted several promising ideas for improving sound insulation in ventilated windows. Metamaterials offer greater flexibility in frequency bands, potentially allowing for customization tailored to specific projects. Several alternative metamaterial-based approaches have shown noise reduction potential above the 10 dB threshold, although often in narrow frequency bands. Currently, the effective inclusion of metamaterials in real window design seems challenging, because some critical issues need to be addressed in the application to real-world scenarios:

- Possibility to incorporate the designs proposed by researchers as replacements or, more likely, complementary to conventional windows;
- Adequately demonstrate that, in addition to acoustic and ventilation performance (to be qualified according to a more standard approach), the proposed design can also ensure compliance with the visual aspect;
- Innovative window solutions aiming to replace conventional windows must meet basic expectations of functionality and aesthetics, as well as the requirements of building regulations.

In summary, for the implementation of ventilated and acoustically controlled windows, new studies should address the following points:

- Establish standardized test methods for acoustic and airflow assessments or at least identify a minimum set of parameters to be used for qualification and comparison, providing a reference frequency range and reference airflow conditions and specifying optimal methods for numerical simulation and on-site measurements, including ventilation under natural and wind conditions;
- Define reference cases involving both conventional and innovative windows that can help to compare proposed solutions and identify the best compromise between acoustic insulation and ventilation, without neglecting the visual functions of a window.

3. MEASUREMENTS CAMPAIGN

All above considered, it is therefore extremely important, particularly in the research and development phase, on the one hand to define a correct methodological procedure to address this problem in a repeatable and reproducible way, on the other hand to combine traditional laboratory measurements with a series of studies in real environments that allow to verify the actual overall performance of the elements under study in a context that reproduces as faithfully as possible the complexity of the building environment, with its multiple interactions of thermal, ventilation, mechanical and acoustic effects.

To this end, a preliminary study will be carried out in parallel both in laboratory conditions (full scale) and natural conditions (installation on the façade of an experimental Zero Energy Building, ZEB). The aim is to measure the characteristics of a full-scale acoustic meta-window (AMW), based on the development and engineering of a previous meta-window unit [11], comparing the results with those of a conventional and highly performing window, both from an acoustic and thermal point of view, currently installed in the ZEB experimental building of CNR-ITC.

In particular, the differences in the acoustic insulation and ventilation properties in closed and partially open window conditions will be studied.

This preliminary study aims to provide a characterization of the main properties of the AMW in question but more generally aims to provide a methodology to compare the performances of windows equipped with devices based on acoustic metamaterials with those of a conventional reference window, measured both in the laboratory and in a full-scale experimental building.

The measurements in an experimental building are particularly important to verify the laboratory results in an environment that reproduces the complexity of a real building while maintaining adequate control of the experimental conditions.

3.1. Full-scale AMW

As pointed out in a previous study [14] once the actual size of the AMW to be used for the full-scale tests has been chosen, i.e. the same size as the conventional window currently present in the ZEB building, a FEM (Finite Element Method) analysis of the acoustic and ventilation performance characteristics must be conducted prior to the experimental studies.

Fig. 2 shows a comparison between the unit AMW (40x40 cm) [11], the intermediate scale AMW (80x120 cm) [11], and the full-scale AMW under study (117x147 cm), comparable with the window currently installed in the ZEB. The FEM investigation on the scalability of the proposed AMW is being done at University of Bologna [15].

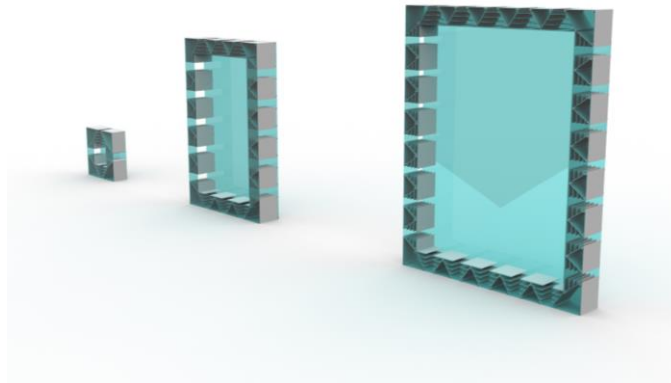


Figure 2 – Comparison between the unitary AMW (left) [11], the intermediate scale AMW (center) [16], and the full-scale AMW (right) under study [14, 15].

3.2. Laboratory measurement of sound insulation

The acoustic insulation properties are characterized in laboratory conditions in the CNR-ITC coupled chambers for the measurement of the sound reduction index according to ISO 10140-2 [17].

In particular, in the laboratory, not only is the sound reduction index of the closed AMW measured, but also in the open configuration.

3.3. Façade sound insulation

The measurement of the façade sound insulation with the global method using a loudspeaker, according to ISO 16283-3 [18], is conducted in the full-scale ZEB experimental building of ITC-CNR, both on a conventional window and on the AMW, positioned in an equivalent way to make a direct comparison of the results.

3.4. Blower door test

Air permeability is measured with the pressurization technique, i.e. with the Blower Door Test, BDT, defined by ISO 9972 standard [19], which allows to evaluate the airtightness of the building when subjected to internal-external pressure differences greater than those due to external climatic forcing. In particular, the BDT is based on the pressurization or depressurization of the building or of a single room and on the simultaneous measurement of the air flow rate that, under an imposed pressure difference between internal and external environment, passes through the façade or, as in this case, the window under study.

This measurement is carried out both in the laboratory and in the ZEB experimental building.

3.5. Measurement of ventilation as air exchange rate (tracer gas decay test)

The measurement of ventilation in natural conditions is performed by determining the air exchange rate using tracer gas, continuously measuring the decay of the concentration of the tracer gas due to the exchange of air with the outside.

The measurement is performed both on the AMW and on the conventional reference window, installed consecutively in the same location of a façade of the ITC-CNR ZEB experimental building.

The window in this configuration is the only façade fixture in a sealable environment (about 41 m³) equipped with a ceiling air destratifier, which is digitally controllable to ensure the mixing of the air in the internal environment, guaranteeing the lowest possible air speed in proximity to the window being studied.

4. CONCLUSIONS

The methodology adopted with this PRIN demonstrates the effectiveness of the selected acoustic metawindow (AMW) [11] using the relevant standard methods and comparing the natural ventilation and sound insulation values obtained with those of a high-performance conventional window. This preliminary study aims to provide a characterization of the main properties of the AMW in question but more generally aims to provide a methodology to compare the performance of windows equipped with acoustic metamaterials with those of a reference conventional window, measured both in the laboratory and in a full-scale experimental building.

The METAWAVE project includes a FEM (Finite Element Method) analysis of the acoustic and ventilation performance characteristics [14, 15]. Then, in the CNR-ITC acoustic laboratory, the sound insulation of the AMW, both closed and partially open, and the air permeability through the blower door test will be measured. Finally, measurements will be carried out in a full-scale experimental building, in

order to verify and contextualize the laboratory results in an environment that reproduces the complexity of a real building while maintaining adequate control of the experimental conditions.

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