BUILDING FACADE AS A POTENTIAL AEROACOUSTIC NOISE SOURCE

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Abstract:

Contemporary architecture and modern building technology allow for erection of tall buildings with advanced energy efficient building skins. Transparent double skin facades (TDSF) belong to those walls claddings systems, that are developed from various points of view and attract attention of researcher from different scientific fields. In our research we deal with possible impacts of cavities, such as ventilation inlets, or other wanted or unwanted openings in the transparent wall claddings on the occurrence of aeroacoustic noise, caused by high windspeeds on building façades. Sounds produced by airflow depend not only on its speed, but also on shapes and sizes of cavities or obstacles. Sound amplitudes and frequency spectra, ranging from tonal sounds, sounds with pulsating components or broadband noises can occur depending on situation and contribute to overall acoustic discomfort indoors and outdoors. This paper summarizes and explains the basis of most common sounds that might be caused by airflow on upper floors of tall buildings during windy days. Based on the two preliminary studies performed in high-rise buildings with TDSF in Bratislava, a detailed analysis of measured sounds caused by wind is shown, the difficulty to detect the problem is described and several questions on wind-induced noise on buildings are opened.

Keywords: *wind induced noise, high rise buildings, aeroacoustics, acoustic measurement, noise pollution acoustic sustainability, transparent double skin building facade*

1. INTRODUCTION

Increased amount of tall buildings in European urban areas has brought many new questions on wind, daylight and acoustic comfort. Prediction of wind comfort of pedestrians close to building facades and calculation of shadowing effects of buildings belong to nowadays well-known practice, typically delivered as parts of project documentation. Recent studies have also shown a growing interest in prediction of noise in so called street canyons, since traffic noise is often amplified due to multiple sound reflections from acoustically hard building facades [1]. New types of building constructions, such as adaptive facades or double skin facades in combination with increased building heights are opening also new questions on wind induced sounds on buildings. One of the main problems is the complexity of building structures in comparisons with aeroacoustic studies on e.g. airplanes, which are hermetically closed and thus don't have air inlets or openings on the main construction and don't contain periodic shading elements in front of the windows.

Wind induced noise is very often overlooked in the design of façades [2,3]. This paper therefore summarizes most common wind induced noise mechanisms and possible investigation methods that can be used to indicated whether there is a potential for a presence of aeroacoustic noise caused by building façade.

2. BASIC THEORY AND STATE OF THE ART

In fluid dynamics theory, two kinds of airflow can typically occur: laminar and turbulent. Laminar flow is present at low velocities of fluid, where particles move at straight lines following its smooth path and do not interfere with another. Tubulent flow occurs when the velocity is so high that the fluid layers do not move in a straight line anymore and velocity is thus not constant at every point. In order to predict flow patterns in different fluid flow situations, and to decide whether the flow is laminar or turbulent, Reynolds number (Re) is used. Reynolds numbers smaller than 2000, indicate that flows tend to be dominated by laminar flow, while Reynolds numbers larger than 4000 are typical for turbulences. (The Reynolds number is the ratio between the fluid's inertial force and its viscous force.)

In aeroacoustics, sound is a typical result of a turbulent fluid motion, where aerodynamic forces interacting with surfaces or by flows variations in regular periods. The theory of sounds produced by airflow is used in many different scientific fields. One of the most known sounds produced by air flow are sounds produced by vocal chords, such as speaking and singing. These are based on biomechanical movements of vocal chords that control air flow of expiratory air for the production of sounds. Another application of this theory can be found in the development of musical instruments (wind instruments), where sounds are produced in a cavity of an instrument, tuneable to different frequencies. Turbulences play here a significant role. Aeroacoustic noise produced by airplanes, trains and other vehicles and design of pipes and ventilation tubes has been over many years also investigated by many researchers. In literature, lots of information can be found on mentioned topics, however only limited research studies concern wind induced noise by buildings or their components [4].

Wind induced noise, especially "on buildings", have been in more detail investigated in the beginning of 21st century. In [5] the experiments were performed in the wind tunel for typical and smooth section of a window frame (Fig.1). It has been shown, that in general the sound pressure level and pitch increases with wind speed. In cases with constant wind speed, sound pressure level decreased with a width of the gap. In case of "smooth section", the onset of aeolian tones was not present for gap widths smaller than 1 cm, whereas in case of "typical section", tones were present up to 5 cm. It has been confirmed that the presence of sharp edges is responsible for generation of so called aeolian tones. Aeolian tones are produced by airflow when it passes around or through objects. Based on empirical data on a cylinder, an aeolian tone will have a frequency f = (St.v)/d, where "St" is a Strouhal number [6], "v" velocity and "d" diameter of a given cylinder.

Experiments in [5] have also shown that so called aeolian tone generation depends on the gap width in the window. It has been proven, that for a gap with a width smaller than 5 cm there is a linear relationship between the wavelength of the produced tone and the width of the gap (Fig.1). In this experiment, also empirical formula was proposed in which the wavelength is equal to ca 31,5 x width of the gap. This study has also shown, that in case of small gaps (< 5 cm), the noise level is dominated by aeolian tones, whereas for larger gaps the noise is caused by low frequency turbulence (below 63Hz) in the jet stream (without a presence of aeolian tones).

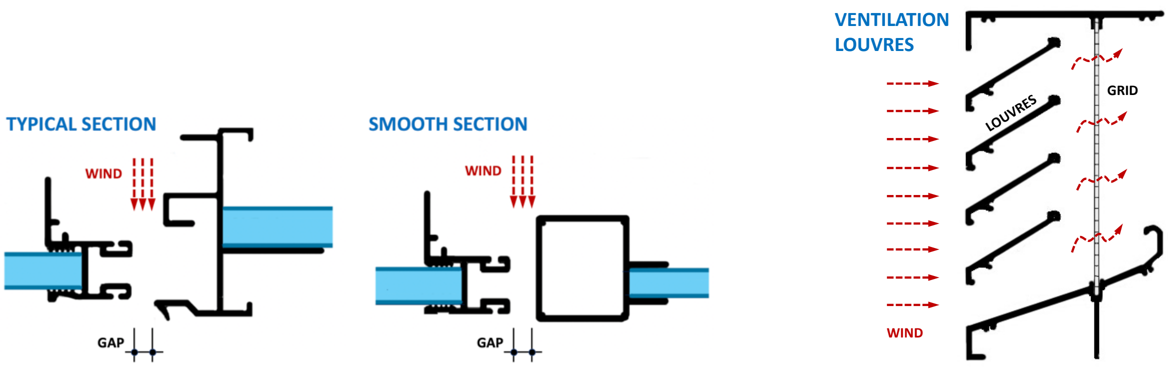

Fig. 1: Left: Illustration of the window cavities, used in the experiment on noise generated by accelerated air flow through window [3]. Right: Example of ventilation louvres used in double skin transparent facades.

In 2010 a summary of all known aerodynamic noise sources such as vortex shedding, cavity resonance, structural resonance and building elements that can be responsible for such noise have been discussed in the work of [7]. In 2015 an assessment of the potential wind induced noise have been discussed in relation to building design and Arup Acoustics guidance notes [8] [9]. The possibility to use computational fluid dynamics (CFD) for prediction of vortex shedding from sunshade elements has been shown in terms of prediction os aeroacoustic noise. Several recommendations for practical consulting and engineering praxis have been listed, and discussed such as, "unsealed slots and exposed elements within facade cladding, should be larger than 10 cm" and when cannot be avoided needs to be applied with damping treatments. In [6], noise from louvre blades of 15 cm was also measured. In order to avoid cavity resonances, they recommend to close openings and cavities larger than 10 cm.

According to the [9], wires, circular cables or hollow sections with diameter largen than 5 cm should be avoided or provided with special damping treatment. Array elements with dimensions larger than 10 cm should be irregular or should use larger dimensions of apertures. Description of aerodynamic sound, i.e. noise generated from fluid flow is described in [10]. It is also shown, that aerodynamic noise at low wind speeds has usually tonal character (known also as "aerodynamic whistle").

3. CASE STUDIES

Two high-rise buildings in Bratislava, with transparent double skin facade were chosen in our study. Building 1 has quarter cylindrical shape and height 32 floors. Building 2 is a rectangular shape with 23 floor. Our main interest was to detect different types of aeroacoustic noise that might be caused by TBSF. In the first case (Building1) a tonal sounds were present, caused either by an open cavity, semi open cavity, shape edges or periodic structure. The second case study (Building 2) shows an example of a typical sound produced by small opening or a slit resulting in generation of a narrow band sound with increased pitch in increased wind speeds.

3.1 Case study 1

Sound recordings were made in one of the offices on the 23 floor of a tall administrative building 1. Measurement was done during a relatively windy day with all windows and doors closed. Workers however reported that sound is audible also during not extremely noisy days. Three recordings were chosen for this article. First one was performed at moderate wind speed and second two in extremely windy situation.

Recording No.1 (Fig.2) shows strong and clear tonal components with dominant frequency around 6 kHz and harmonic frequencies at 9 kHz and 12 kHz. The fundamental frequency of the "whistling sound" is at 3 kHz and it is ca 40 dB weaker than its harmonic component at 6 kHz. The wavelength of a tone with frequency 3 kHz is around 10-11 cm. This means that the construction of a facade either contains a cavity with corresponding dimensions (e.g. 5 cm, 10 cm etc), Helmholtz resonator or sharp edges combined with gap widths.

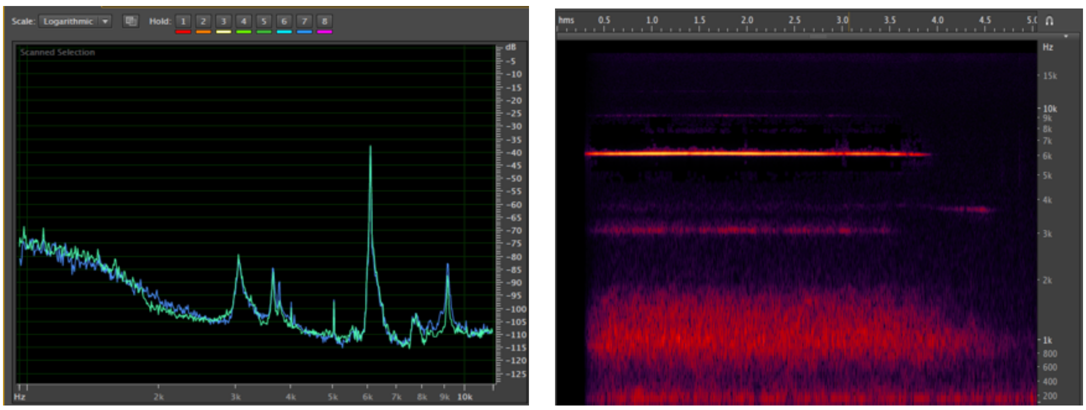

Fig. 2: Recording 1. Example of the FFT spectrogram, based on recording in the office (left) and spectrogram in time (right)

Figure 3 shows results of the recording 2 and 3 (situation with higher wind speeds). Interestingly, several tones are present, changing over time. This might be due to presence of different cavities or periodic surfaces, and different wind directions. Large number of tonal components generated by the aeroacoustic noise measured in the office, also explains very high sound levels with great annoyance potential.

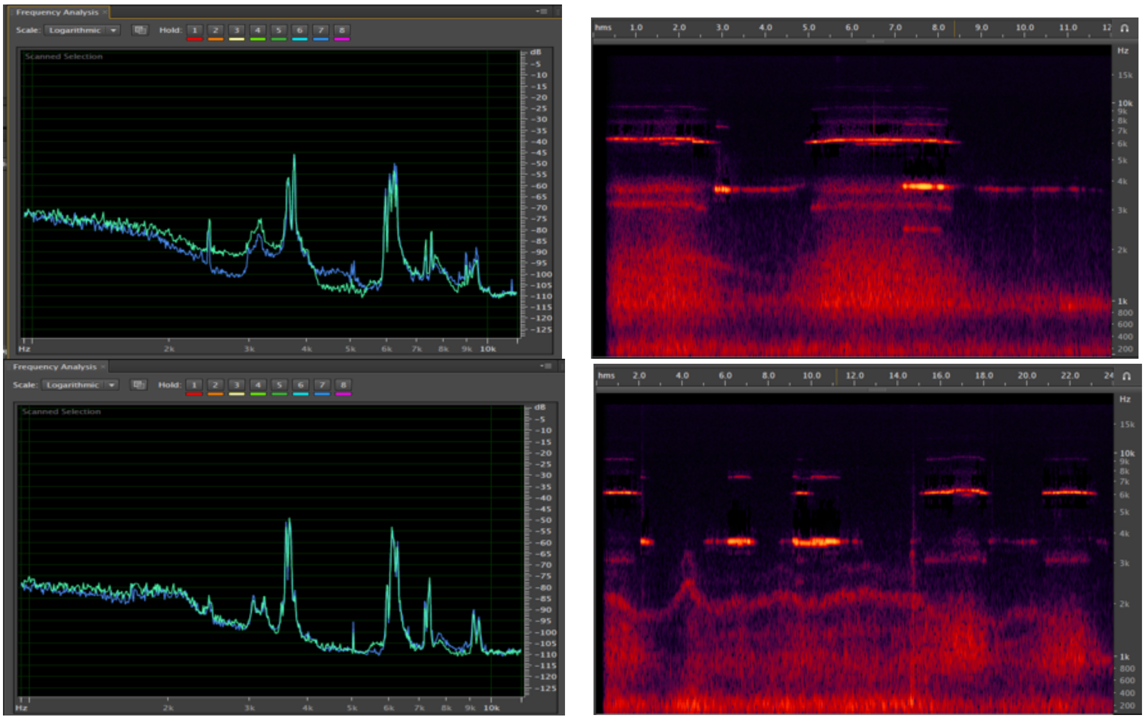

Fig. 3: Frequency spectra (left) and spectrograms (right) of the Recording 2 (upper figures) and Recording 3 (lower pictures).

If we look at the type of construction of the facade (or similar facades) and their details [11], we will see that the reason for “whistling sound” can have many explanations. Shape of ventilation louvre blades in the air inlet is also shown in the Fig.1 (right). In the cross section of the facade, we can see openings with air inlets regularly distributed and with periodic structure and several cavities with dimensions of ca 10 cm. Based on the simple in situ measurements it is very difficult to precisely identify the reason for each component of the whistling sound individually. Laboratory measurements in wind tunnel of a fragment of the facade would be needed.

3.2 Case study 2

Building 2 has different type of DSTF construction in comparison with the case study 1. The building 2 is not air-conditioned, and for this reason, users tend to ventilate their offices by opening windows to the cavity. Indoor temperature in in the building is regulated by ceiling cooling system, however the air quality in the offices is without ventilation very bad. In case there are several people in meeting of seminar rooms CO_2 concentration is far higher that limit values and humidity of the air is very high.

During windy days (which are in Bratislava region not an exception), audible noise is present in most of the floors. Recordings used for our study were performed in July on the 7th floor with opened window to the cavity of the DSTF. Measured sounds in this case haven’t reached as high intensities as in case of the noise measured in building 1 and the character of sound was also very different from the one measured in the case study 1. Here, the most dominant sound was a narrow band noise around 600 Hz, with changes in pitch due to changes of wind speeds.

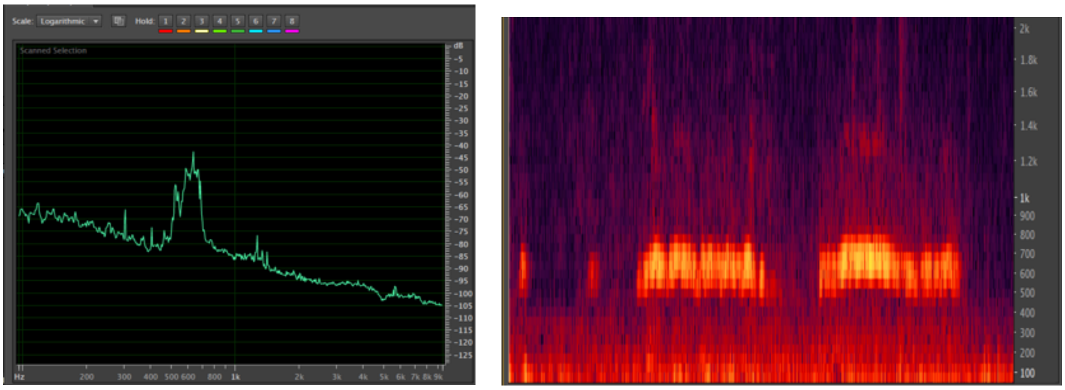

Fig. 4: FFT and Spectrogram of the recording made on 7. floor during summer time

4. CONCLUSIONS

Our preliminary study on real buildings have confirmed findings from laboratory experiments performed by other authors, such as presence of small openings in the facade construction and periodic structure, such as louvres have high potential for aeroacoustic noise. and that. Real case situations are however much more complex for analysis, since several effects might occur at the same time. The complexity of building facade doesn't allow for investigation of different elements with potential for wind induced noise per-partes. For more detailed investigation a laboratory investigation of a building facade element would be necessary.

ACKNOWLEDGEMENTS

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