Building and Environment 110 (2016) 148–160

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Assessment of sound insulation of naturally ventilated double skin facades

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A R T I C L E I N F O

Article history:
Received 13 July 2016
Received in revised form
7 October 2016
Accepted 11 October 2016
Available online 12 October 2016

Keywords:
Double skin facade
Sound insulation
Prediction
Acoustic measurement

A B S T R A C T

The sound insulation spectrum is analysed of 18 double glazing arrangements facades, of which 9 double skin facades were measured *in situ* and 9 in a laboratory setting. The influence of the cavity thickness, the parallelism of the two glass panels, the absorptivity of the cavity and the effect of the size of ventilation slots are investigated. The results are compared with double layer wall insulation prediction models. Also a new, simple model is proposed that predicts the sound insulation of naturally ventilated double skin facades, based on the coincidence frequency, the structural resonance frequencies, the cavity resonance frequencies, the façade construction, the dimensions the and material properties. The model predictions are validated by measurement data.

1. Introduction

Double skin facades (DSF's) are used in more than half of countries in Europe (27), with the incentive to save energy in the winter period. Most frequently they are implemented as a part of envelope structures in large administrative buildings. The state of the art design of DSFs is the result of many years of research and development in the fields of structural and material design, thermo-technology, daylight and acoustics. DSFs typically appear as elements of intelligent building concepts. Research has been performed to achieve the most effective combination of heating and ventilation through openings by making use of integrated logic artificial neural networks [1]. Substantial efforts were spent on performing CFD simulations, measurements and analysis in the field of air flow in the DSF cavity, on the investigation of the influence of the cavity thickness, on the type of ventilation openings, and on façade shading systems [2,3]. The growing emergence of the usage of DSF's has opened a discussion on their influence on fire protection of buildings, propagation of fire by the façade construction and also on their behavior in situations of firefighting [4,5]. The adequacy of the location and size of vents to prevent overheating of the interior in summer time, while allowing for preheating of the room in colder seasons was studied in Ref. [6]. The use of plants in the DSF interspace was also considered as a viable option for limiting heating by sunlight exposure of rooms [7,8].

From a building acoustics point of view, DSF's offer a way to limit indoor noise even in the case of high exterior noise levels. By virtue of their double leaf structure, even if they allow natural ventilation in administrative buildings, they are effective in keeping indoor sound pressure levels caused by exterior noise to reasonable levels [9–13].

A large number of double wall sound insulation studies have been performed [14–18]. One of first prediction models was proposed by Beranek and Work [19]. Their model assumes perpendicular incidence of acoustic waves, which allows to describe the propagation of through a wall by means of a structural impedance approach. An extension of the model to a diffuse sound field, involving oblique angles of incidence, was introduced by London [20]. Later on, White and Powel [21] introduced a model for bounded panels, taking into account the resonance effects caused by their dimensions. A statistical mechanical approach into wall structure characteristics has been implemented by Lyon and Maidanik [22]. Their work was based on analysis of power flow response between two or more coupled multi-resonant systems to

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http://dx.doi.org/10.1016/j.buildenv.2016.10.004
0360-1323/

random excitation, determining the coupling between a reverberant acoustic field and a structure by means of a radiation resistance approach. For calculating the acoustic insulation performance of cavities, Mulhoulland and Cummings [23,24] took into account acoustic wave reflections between the two walls by means of ray-tracing approaches. In 1970, Crocker and Price [25,26] proposed a Statistical Energy Analysis (SEA) method for building structures, taking into account non-resonant vibrations of walls and dynamic stiffness of structural parts. Another impedance model was designed by Mulholland for double walls without absorptive material inside the wall [27]. An alternative impedance matrix method has been developed by Hamad and Tachibana [28]. Au and Byrne [29,30] introduced an impedance transfer function for flexible nonporous materials, which was later on adapted by Ver [31]. The influence on the sound transmission of the mass per unit area, the bending stiffness and damping, damping has been evaluated by Heckl [32]. One of the first models that took into account acoustic bridges due to connections between layers connection was developed by Sharp [33], who found inspiration in the work of London, Cremer and Heckl [34]. Further work on sound insulation in the presence of rigid construction joints was done by Fahy [35]. Plasterboard double walls were evaluated using a statistical prediction approach by Lin, Garrelick [36], Craik, Wilson [37] and by Green and Sherry [38–40].

Concerning the acoustic properties of naturally ventilated DSFs, researchers studied the influence of adding a second transparent layer on facades on their sound insulation [41]. Others studied the effect of adding absorptive material in the cavity of a DSF [42–45]. The most extensive study was done by Blasco, whose aim was to develop a supplement to standards EN 12354-1 and 3 for DSF's [46,47]. He proposed three ways to predict the sound insulation, based on a double wall sound propagation model [48]. DSF sound insulation properties turn out to be influenced by diffraction due to vents on the external facade layer, and also due the finite element of structural elements in general. At low frequencies, diffraction effects can cause a decrease of the accuracy of sound pressure measurements carried out on the external side of building in low frequency range [49]. Diffraction also plays a role with respect to the directivity of sound waves radiated by a slot [50–53]. Barclay et al. stressed the importance of an integrated approach to both noise exposure and ventilation performance in urban buildings [54]. Bibby et al. looked into the use in practice of ventilation grill acoustic silencers [55]. The influence on the acoustic performance of DFTs of the spacing of the vents and of absorptive materials applied in the cavity was studied in Refs. [56,57]. Also extensive comparative studies of the acoustic performance of different DSF types have been carried out [58–60].

This article reports on a sound insulation measurement campaign on laboratory and *in situ* double (transparent) skin structures. Chapter 2 deals with *in situ* measurements of 9 DSFs and with the influence on their construction solution on the sound insulation. Chapter 3 summarized laboratory measurements of double leaf specimens, their sound insulation, and the analysis of the sound field in the cavity. In Chapter 4 the laboratory results are compared with different prediction models. Based on the observations, in Chapter 5, the above mentioned existing sound insulation prediction models are integrated into one simple model.

2. In situ measurements of DSF sound insulation

In situ measurements were carried out in the city of Bratislava on eight DSFs, and one double skin facade element (DSFE) on a dwelling house at Trnava road (DHTR). The measurements were carried out in accordance with standard EN ISO 16283-1 [61], with the addition of one microphone M2 inside of the cavity. Microphone M1 was placed outside the cavity, at 2 m in front of the façade. Microphone M3 was placed in the receiving room inside the building (Fig. 1a). Microphones M1 and M2 were positioned at 1.5 m above ground level. The positions of microphone M3 were in accordance to the recommendations of standard EN ISO 16283-1 (at least six random positions per measurement). The outdoor traffic noise was used as the source of sound, except for some cases, where amplified pink noise was used instead. The measurements were done by class 1 measuring analyzer devices according to the IEC 61672-1 [62]. The room acoustic parameters were determined according to EN ISO 3382-2 [63]. According to the Slovak legislation

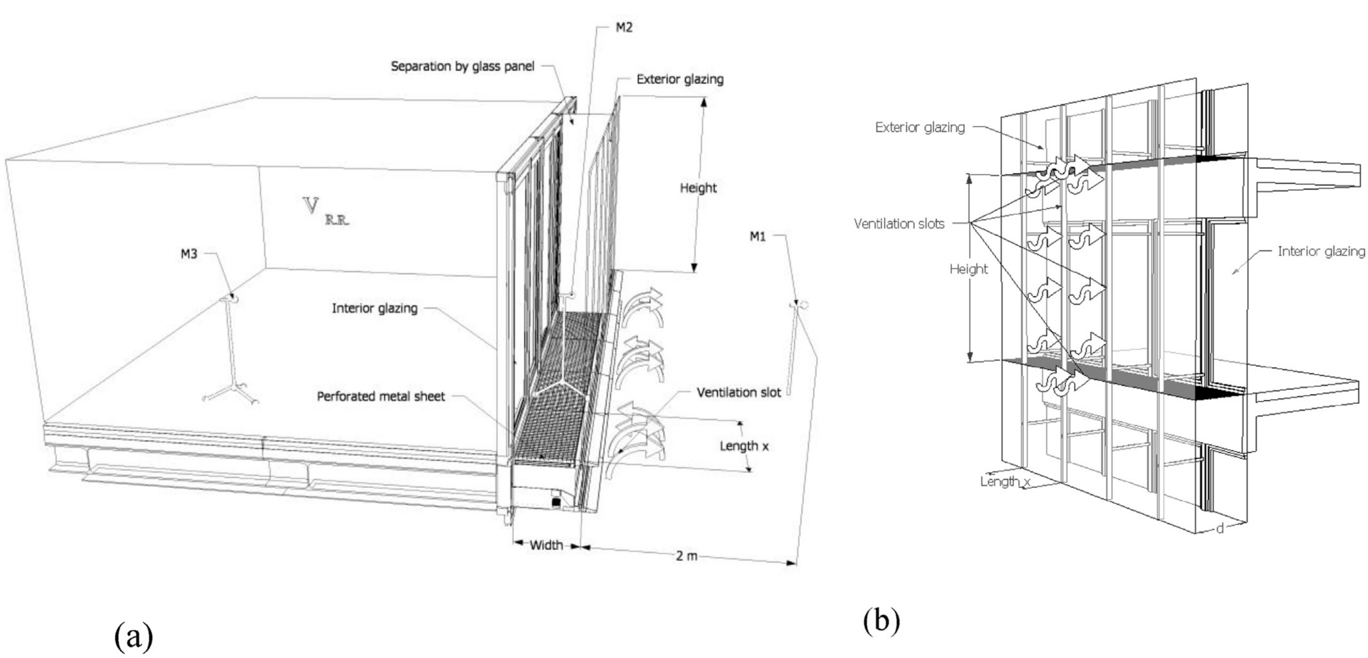

Fig. 1. Scheme of corridor type DSF naturally ventilated by a) grills; b) slots between adjacent glass panels.