Sound propagation within a double skin facade and its influence on the speech privacy in offices

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Summary
Double transparent facades (DTF), as a part of the facade structure of many administrative buildings, have a positive impact on the reduction of the background noise levels in working places caused by traffic noise. However, the space between the two glass structures is acoustically connecting the adjacent rooms (offices) in most of DTF realisations, causing a possible decrease of speech privacy in the offices due to flanking sound propagation. This article focuses on the prediction of the sound propagation between two modelled offices (via the mentioned cavity of DTF) by means of Odeon® software. An actual situation in the National Bank of Slovakia in Bratislava is modelled, where the speech privacy is of a high interest. The influence of the cavity width and shape, as well as the window openings area and background noise from traffic on speech intelligibility is reported.

PACS no. 43.50.+y.Nn

1. Introduction

Double transparent facades (DTF) reduce the sound propagation from exterior into the workplace. However, the space between the two glass structures is acoustically connecting the adjacent rooms (offices) in most of DTF realisations, causing a possible decrease of speech privacy in the offices due to flanking sound propagation [1].

A practical and accurate approach to assess the sound propagation via the air gap in the DTF is by room acoustical ray tracing simulations [2], which allow to calculate several acoustic quality parameters, such as Early decay time *EDT*, Reverberation time T_{20}, Speech transmission index STI, Sound pressure level L_p and Strength of sound *G* values [3]. In the middle and high frequency range, the ray tracing method usually compares well with acoustic measurements for coupled spaces. In spite of their lesser performance at low frequencies [4], in state of the art software different diffraction and scattering algorithms are overall quite adequate to predict room acoustic values. Also speech privacy is an acoustical quality parameter that is crucial the design of large offices and offices in handling multiple clients simultaneously [5,6] (Table I.). In some DTF implementations, the background noise is suppressed to such a low level that the transmission of sound in between offices is not anymore masked, in particular when the office windows are open. Simulation programs can assess the speech privacy in a room acoustical situation indirectly via the inversely related STI.

Table I. Speech privacy and intelligibility dependence.

STI	Speech intelligibility	Speech privacy
0,00 - 0,05	Very bad	Confidential
0,05 – 0,20	Bad	Good
0,20 – 0,40	Poor	Reasonable
0,40 – 0,60	Fair	Poor
0,60 – 0,75	Good	Very poor
0,75 – 0,99	Excellent	No

The models in this article simulate existing offices in the main office building of the National Bank of Slovakia NBS [7]. The influence of the width and shape of cavity, as well as the arrangement of window openings and background noise level on the STI and *G* are studied. Real measured values of background noise are used as boundary conditions in the analysis [8].

2. Description of the experiment

2.1 Description of the case study

A model of two coupled rooms was created on the basis of a real office building (NBS in Bratislava, Slovakia) [7].

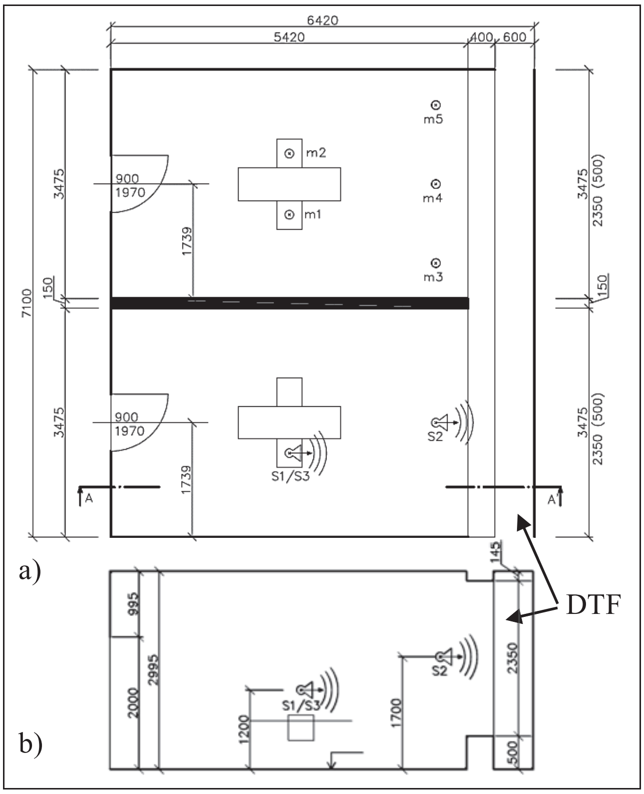

Figure 1. Dimensions of the simulation model with the indication of sound source (S) and microphone (m) positions a) ground plan; b) vertical section

In order to assess the impact of flanking transmission between offices via the DTF, we have set the walls in the simulations as perfectly insulating (100% transmission loss). Three alternatives were used for the sound sources in the sending room:
S1 (middle of the office) and S2 (near to the DTF): speaking person (L_W= 61 dB(A)) at two different positions; S3: omnidirectional sound source generated pink noise (L_W=31 dB(A)) (Figure 1) at the same position as S1. The situation was evaluated for five measuring positions (m1 to m5 in receiving room) and along a 0,1 m x 0,1m grid, 1,2m above floor. All surface material characteristics (sound absorption coefficient, scattering) were compatible with the real situation.

The shape and physical characteristics of both rooms were taken the same.
In section 3, we address the influence on STI, G and the speech privacy of the following determining parameters:

- Background noise;
- DTF cavity width;
- DTF cavity shape;
- Arrangement of open windows.

These parameters were varied as follows.

2.2 Background noise level in different office buildings

Background noise were determined in 10 different office buildings (with DTF) in Bratislava (8 alternatives for situation with open window in office, one for close window- “silent room” and one without background noise- “0 dB”) [9]. The cavity width was taken to be 600mm. The average SPL values of the background noise level is shown for each alternative in Figure 2.

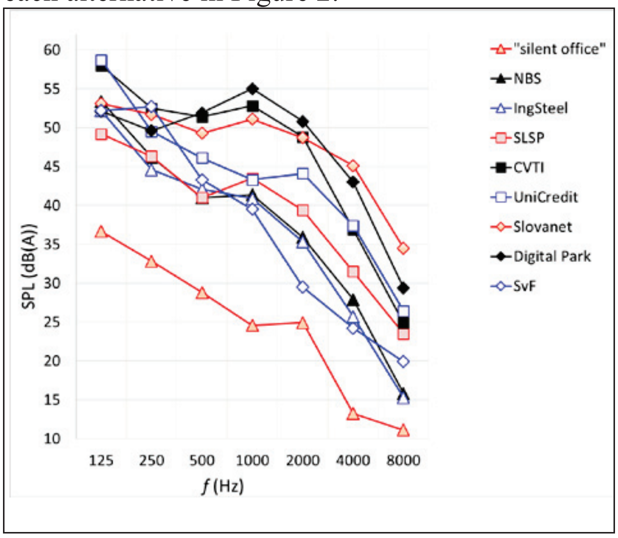

Figure 2. Average values of the background noise

The used abbreviations in Figure 2 are:

NBS-	National Bank of Slovakia;
IngSteel-	IngSteel company headquarters;
SLSP-	Slovak Saving Bank headquarters;
CVTI-	Slovak Centre of Scientific and Technical Information;
UniCredit-	UniCredit Bank headquarters;
Slovanet-	Slovanet company headquarters;
DigitalPark-	administrative complex of office buildings;
SvF-	Faculty of Civil Engineering building;

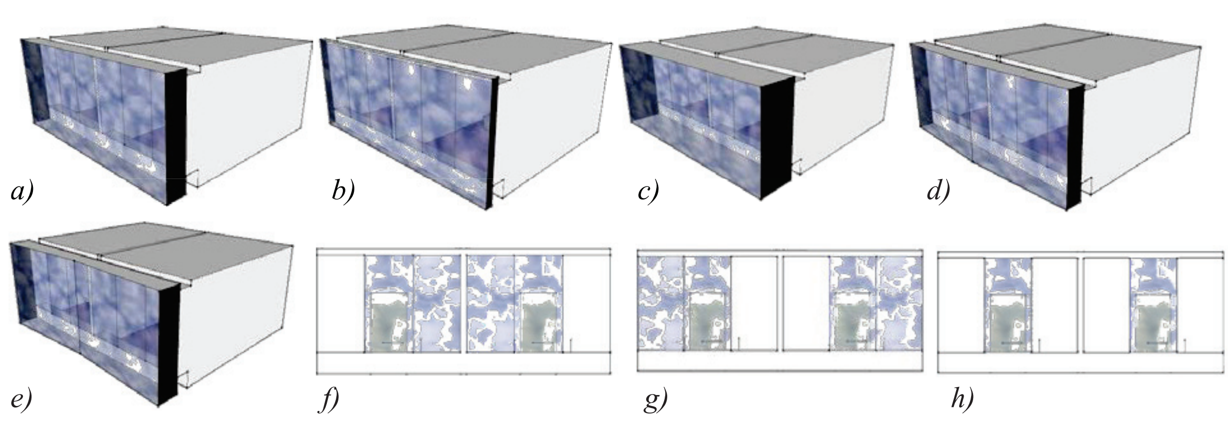

Figure 3. Variants of the DTF cavity. a) standard configuration: 600mm cavity width (parallel shape); b) idem but 200mm cavity width; c) idem but 1200mm cavity width; d) A- shaped cavity; e) V- shaped cavity; f) 141; g)222; h)11211;

2.3 DTF cavity change influence

First, different variants of DTF cavity (based on differences in width, shape and arrangement of opened windows, see Figure 3) were analyzed in terms of the acoustic comfort in adjacent rooms in the absence of background noise.

1. Different DTF (parallel) cavity widths: 200mm, 600mm, 1200mm.

2. Different DTF cavity shapes.
   - Parallel shape (width 600mm);
   - A- shape (cavity width in center 700mm; 500mm on sides);
   - V-shape (cavity width in center 500mm; 700mm on sides);

3. Open window arrangement
   Different combinations of open and closed windows were modeled. The window dimensions were 1158mm x 2350mm.

   - 141 (area of four center modules was closed);
   - 222 (area of two modules on both sides was closed);
   - 11211 (area of center window module of both rooms is closed);

2.4 Quantification of DTF sound insulation: EN ISO 12354-1

EN ISO 12354-1 gives a expression for the normalized level difference for indirect airborne transmission $D_{n,s}$., assuming a diffuse sound field in all areas [10].

$$D_{n,s} = R_{hs} + R_{hr} + 10\log\frac{A_h \cdot A_0}{S_{hs} \cdot S_{hr}} + C_{pos.gaps} \quad (1)$$

$C_{position\ gap}$ depends on the geometry of the openings and facade structures. In this case, the DTF interspace can be considered considered as a corridor, which is transmitting sound from the sending to receiving room (1). If the angle of openings is 90° and the spacing between is less than 1 m then $C_{position\ gap}$ is set to -2 dB. If you are in one plane and the distance is greater than 1 m, then $C_{position\ gap}$ = 0dB.

3. Results and discussion

3.1 Impact of background noise level on

As a consequence of masking effects, background noise level has a direct influence on speech privacy and respectively speech intelligibility. The simulation results show that the differences in background noise levels in Figure 2 result in variations in STI values of the order of 0.4 (40%) (Figure 4), with a maximum of about 70%. The simulation of a silent office with only operation noise present results in STI values between 55% and 65%.

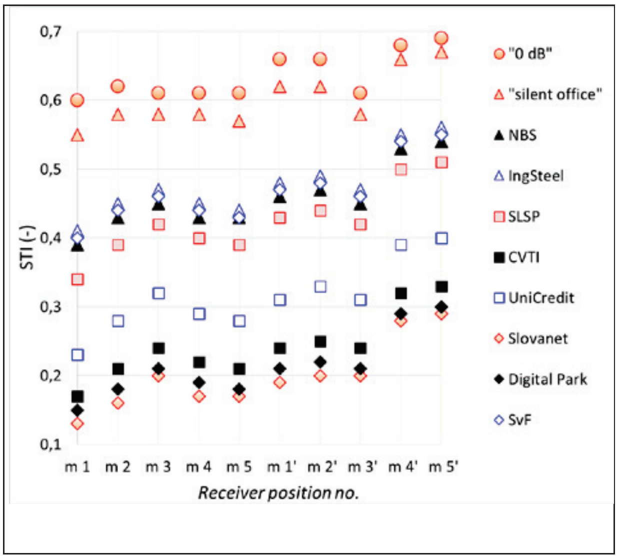

Figure 4. Background noise change impact to STI in different receiver positions. m1- m5 (S1 source-speaking person); m1'- m5' (S2 source-speaking person)

In this paper presented simulations analysis generally says that, the background noise in a DTF cavity has to be higher than 62 dB, for sufficient masking the speech from neighboring office rooms. Many international companies operating office buildings in which acoustic measurements were carried out are using the premises 24 hours a day (night shift, marketing and communication with partners on the reverse side of the globe).

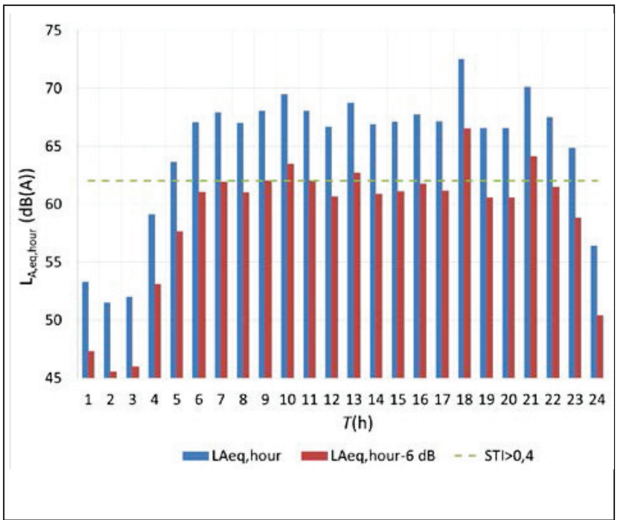

Figure 5. Traffic noise spectrum along a busy street in Bratislava in front of (blue) and behind (red) a DTF. The dashed green line depicts the speech intelligibility threshold level of 62dB

The blue curve in Figure 5 depicts the equivalent sound pressure levels obtained from the 24-hour measurement along a busy street in front of an office building in Bratislava. Typical noise reductions by a DTF amount to about 6 dB, giving the red curve in Figure 5. The green dashed line depicts the intelligibility threshold. For the considered situation speech is masked only during traffic peak hours. (8:00- 10:30; 12:00- 12:45; 16:30- 19:00; 20:15- 22:00).

3.2 DTF cavity features

Increasing the vertical cross section area of DTF cavity (in the center between rooms) increase the STI values. In order to assess the significance of those effects, it is useful to compare them with the smallest "hearable differences". Given that (ISO 3382), the Just noticeable difference (JND) for STI = 0.1,

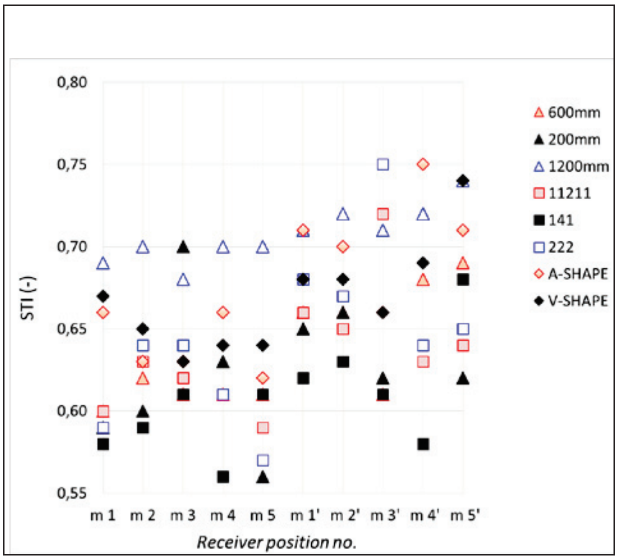

Figure 6. DTF cavity change impact to STI. m1- m5 (S1 source-speaking person); m1'- m5' (S2 source-speaking person)

The differences between the receiver positions in Figure 6 can be considered not to be significant.

In the parallel cavities (200mm, 600mm, and 1200mm), the STI values increased with the vertical cross section of the DTF area.

When changing the cavity shape (parallel, A-shape, V-shape) while keeping the cavity volume fixed, that the vertical cross section has a highest impact on the results. Therefore, the A-shape result in the highest STI values.

Opening windows obviously decreases the STI values. That is why model 141 shows the best results in speech privacy and why models 222 and 11211 have more less equal results.

Also the sound strength G was calculated by using omnidirectional sound source (L_w=31dB) with a pink noise frequency characteristic.

The A-shaped and V-shaped DTFs of 600mm and 1200mm wide the G values results are more or less the same for all receiver positions. For the narrow DTF of 200mm, except for location m1 the results are 5-6 dB lower than for 1200mm.

Opening windows obviously has a strong influence on the sound propagation between the rooms (Figure 7), Model 141 yields the best speech privacy (G decreases with 6-8 dB). Going further from the open window increases the speech privacy with about 2dB,

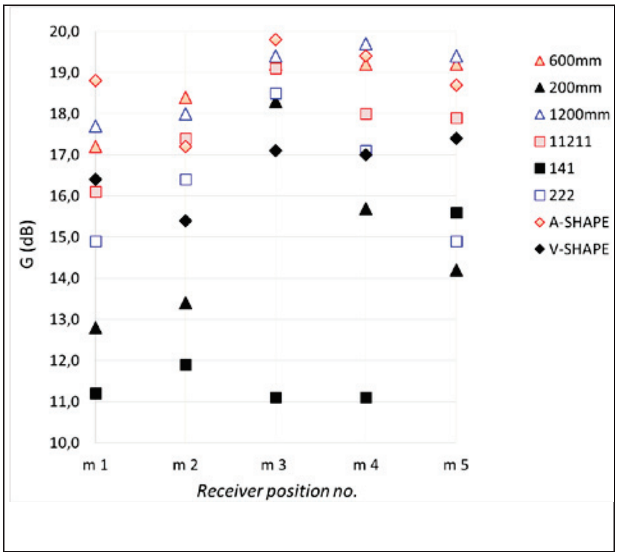

Figure 7. Dependence of G on the position for different DTF cavity shapes (S1 source-speaking person) (S2 source-speaking person);

3.3 Calculation according to EN ISO 12354-1

Table II. Comparison of simulated (Odeon) and calculated (according to standard EN ISO 12354-1) values of average $D_{n,s}$;

Model	ΔL_p [dB] ODEON	$D_{n,s}$ [dB] EN ISO 12354-1
600 mm	12,4	10,2
200 mm	16,1	7,2
1200 mm	12,2	12,7
A - SHAPE	12,2	8,7
V - SHAPE	14,3	11,7

The normalized level difference for indirect airborne transmission $D_{n,s}$ was calculated by using equation (1). The correspondence with simulations is only satisfactory for the case of parallel layers, where the width of the cavity is close to the real width of corridors (more than 900 mm).

4. Conclusions

A general outcome of our study says that if the background noise in a DTF cavity is lower than 62 dB, we will understand the speech from neighboring office rooms. STI is most sensitive to vertical cross section area of cavity. When decreasing the overall width of the DTF, also the STI and G values decrease. The differences between different locations in the room are small. For non-parallel and thin cavities, the expression for the sound insulation between two spaces proposed in EN ISO 12354-1 gives different results than the simulations.

Acknowledgement

This project has been funded by support of the agency VEGA no.1/0358/13 and University Science Park of STU Bratislava.

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