SUSTAINABILITY, ACOUSTICS AND FACADES

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1 INTRODUCTION

Double skin facades are increasingly being used in commercial buildings such as offices, shopping centres, and in schools, as a result of their positive effect on the energy consumption of a building. However, these systems also have an effect on the acoustic performance of the building, in terms of noise exposure to the facades, sound insulation and privacy. The purpose of the double skin facade varies from the simply architectural, controlling solar gain, providing ventilation routes (e.g. "stack effect") or to provide winter gardens and balconies.

The facade elements are often chosen to be an integral part of the building design well before the acoustic consultant is involved. This can have interesting implications to privacy & sound insulation of the building including the positive effects of improvement to building envelope performance, or potentially detrimental effects on privacy, depending on the exact configuration used.

The information presented is a consultant's view of the issues associated with these novel facades when considering sound insulation and privacy of a building, and as such is limited by the time constraints and available information.

2 ENERGY EFFICIENCY

Agreements such as Kyoto, and the recent "EU energy performance in buildings directive" have led to legislation dictating the energy performance of buildings in the UK, such as Part L "Conservation of Fuel and Power" [2] of the building regulations, leading to improvements in the energy efficiency of new and existing buildings, thus reducing the contribution to greenhouse gas emissions.

Whilst the main thrust of this legislation is towards air tightness, and efficiency of the mechanical ventilation systems, there are obvious connections with thermal loading of buildings associated with solar gain in summer and heat loss in the winter. Double skin facades can be used by services designers to control solar gain, acting as a thermal buffer between the temperature controlled and mechanically ventilated environments of the building from the outside world.

3 DOUBLE SKIN FAÇADES

In this paper, a double skin façade refers to areas of the building envelope containing two widely spaced separate glazed layers. Traditional double glazing is not considered to constitute the two skins, but could form one of the glazed layers.

The specific acoustic issues identified concern the sound insulation and privacy afforded by such constructions. These can be affected by:

- Cavity geometry and depth
- Acoustic absorption in the cavity
- Ventilation penetrations in outer skin
- Configuration and geometry of any internal openable windows

A basic analysis of typical outer façade configurations and the effect of these on sound insulation and privacy will be conducted. To simplify matters, the following configurations will be examined.

- Type 0: No external screen (this is the base case)
- Type 1: An external glazed screen stepped off the building facade
- Type 2: A sealed façade with common void over several floors
- Type 3: Fully sealed or secondary glazing

The list of configurations discussed is by no means exhaustive – there are many variants/hybrids of these systems. In later sections, these simplified models will be expanded to include a case study.

3.1 Building Envelope Sound Insulation

The additional external skin of a double skin façade can contribute to the overall sound insulation performance of the building envelope from external sources. However, the degree to which the sound insulation is improved depends on the configuration of the glazing, for example the form of any penetrations in the façade for ventilation purposes, the geometry of the cavity within the façade including surface finishes, and the sound reduction index of the materials used.

Unlike simple cavity masonry walls, or standard sealed secondary glazing, double skin façade buildings are usually glazed, with little opportunity to incorporate acoustic absorption, usually for architectural reasons.

The effect of the extra façade on sound insulation could, however, allow the performance of the inner glazed facades to be reduced.

3.2 Speech Privacy between Spaces

With windows closed, it is likely that there will be no privacy issues associated with double skin facades. However, when two or more windows open onto the cavity, there is a potential path connecting two possibly private spaces. Sound can transmit from one window to the next via the reverberant cavity. This could be potentially disturbing, and cause privacy issues.

4 SOUND INSULATION

In this section we will discuss the sound insulation issues associated with the configurations of façade identified. The following assumptions are made in these discussions:

4.1 General Assumptions

The dominant noise source is likely to be road traffic, so we will assume a quasi line source. In practice, there are likely to be localised hot spots near the tops of adjacent buildings caused by roof top plant. However, for simplicity, these will be ignored.

The building is in a built up area, with plenty of similar tall buildings nearby. These “hard corridors” of buildings are not very absorptive, and hence noise is not easily dissipated. As such, traffic noise does not readily drop off with height as expected from a classical line source until the top of the neighboring buildings. This effect is commonly known as the ‘anyoneffect’[3] and is well documented.

Finally, it will be assumed that the neighboring facades are smooth, flat homogenous glazing, with little diffusion, or absorption associated with them; simulating a modern glazed office blocks

In summary, we are assuming a uniform sound field is incident on the façade of the building, with the noise source notionally at the bottom of the façade from road traffic.

5 FACADES

The following section discusses the basic noise levels incident on the inner façade of the building in the presence of generic outer façades, demonstrating concepts of propagation. .

5.1 Type 0: No Screen

Assuming the uniform soundfield outlined, the noise level incident in this scenario would be constant with building height.

5.2 Type 1: External Screen

This configuration is sometimes referred to as a “rain screen”. As this façade is open at the bottom and sides, it effectively acts as a hard duct, transmitting sound up the façade. Once sound enters the cavity, there is no where for it to dissipate, and so propagates relatively unchanged up the height of the building (which could be considered similar to the canyon effect).However, if the noise levels are controlled at the openings (e.g. screened from road), it would be possible for this façade to reduce noise ingress into the building, although this would be limited. The sound insulation performance of an external screen is in part dictated by the materials used (i.e. glazing performance), and by the size of any ventilation openings contained within the glass.

5.3 Type 1a: External Screen with Openings

This is a common variant on type 1, which contains openings or breaks for ventilation purposes.

The openings in the screen would dissipate a small fraction of the sound energy in the cavity, allowing a reduction in traffic noise with height. However, the openings severely limit the overall composite sound reduction capabilities of the outer skin; for example a glazed screen consisting of R_w30 glass with a 10% open area for ventilation would be likely to achieve a practical sound reduction index of around R'_w10. This has been confirmed in practice by Oesterle et al[1].

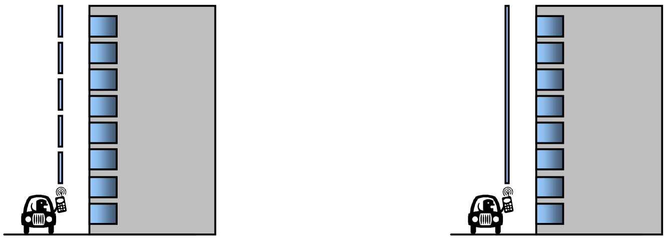


Figure 1: Type 1 and 1a - external screen (1a with openings)

5.4 Type 2: Sealed, with common void

If large opening areas are not required for ventilation purposes, the whole façade could become glazed, forming a box around the inner skin of the building. The effect of this is to seal the façade on all sides; which will result in the cavity behaving (to a limited degree) as a semi-reverberant field, all be it with a rather non-sabine characteristic due to the aspect ratio of the space. However, due to the glazed requirement of the façade for daylight, it may be difficult for architectural reasons to accommodate acoustic absorption into the cavity to control the reverberant field

Therefore, the potential increases in sound insulation of the additional skin can be seriously limited by this reverberant field. Additionally, as in regular double and secondary units, there is also the possibility that standing waves, coincidence effects and other geometric phenomenon could also affect the overall performance achieved.

5.5 Type 2a: Sealed with common void and vents

The acoustic environment in the cavity will be reverberant as Type 2, although the intrusive noise level in the cavity is likely to increase, (depending on the performance of the ventilators). These are likely to be open slots (rather than acoustically rated vents), to achieve the ventilation requirements.

Noise break through the ventilators is likely to locally increase façade noise exposure around them.

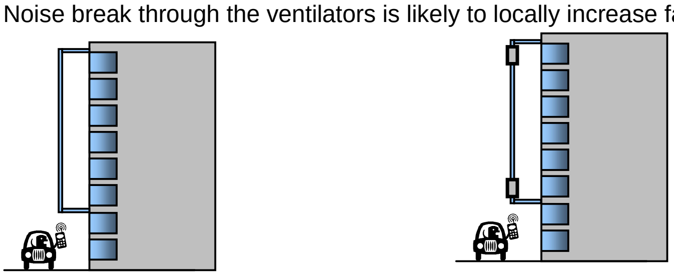


Figure 2: Type 3 and 3a – sealed façade with common void (and 3a with ventilators)

5.6 Type 3: Fully sealed or secondary glazing

The performance of fully sealed or secondary glazed options are well documented and investigated elsewhere, and so will not be discussed here.

5.7 Cavity Absorption

Most facades do not contain significant amounts of absorption or diffusion in the cavity, due to the predominantly glazed finishes. This semi reverberant space could cause intrusive noise to build up, ultimately limiting the potential of the overall build up.

An obvious solution to this problem would be to incorporate some acoustic absorption, however, with the facades being predominantly glazed, there is little space for traditional acoustic absorbers such as mineral wool. Additionally, these would be visible from the outside of the building, potentially ruining the architects "vision" or "statement" of their building.

Whilst there are semi-transparent acoustic finishes available which could be incorporated into the building, for example RPG's Clearsorber[4], it can be challenging to persuade an architect to incorporate these into the design, due to cost or maintenance reasons.

6 PRIVACY

Privacy is not a major consideration with double skin facades until you introduce openable windows or ventilators into the inner façade.

6.1 The Problem

When an occupant of a single skin façade building opens a window, noise from the open window propagates unimpeded, and is unlikely to reflect back to the building (as shown in the figure below). A small amount of sound energy could diffract to adjacent open windows, or alternatively be reflected by unfortunate window geometry; however these effects are likely to be small.

For the double skinned case, the hard, acoustically reflective outer skin reflects energy back into neighboring rooms, and also provides a semi reverberant enclosure for indirect routes. The net effect of this is to degrade the sound insulation naturally afforded by a traditional open window, and thus decrease privacy between two spaces.

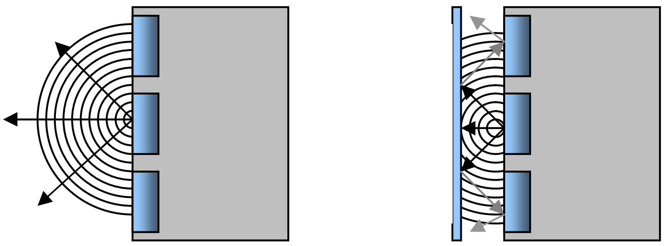


Figure 3: Effect of reflections on privacy (left - no screen, right – screen & reflections)

The degree of this depends again on the geometry of the facades and windows; and the amount and distribution of absorption in the cavity. Additionally, the sound insulation effects outlined in the previous section alter the relative masking noise, which also affect privacy.

6.2 Items affecting Privacy with Double Skin Facades

Many items affect the privacy afforded between two spaces. One item to be considered would be the change in privacy an occupant would perceive by opening a window. For example, in an open plan office, privacy between workstations is likely to be low due to the direct line of sight between users, and so acoustically linking open plan office spaces to other spaces may not present a significant change in privacy. An issue could exist when a private space is linked to another space by the cavity, especially if there is no visual link (and someone could be unwittingly over heard).

Another factor to consider would be the opening area of the window opening onto the cavity. This will dictate how much sound energy can enter or leave a room. Further, the exact size and shape of those windows (i.e. opening into the room / top hung etc) will dictate how much sound is reflected out of the room and how much back into it.

Once sound energy is in the cavity, the path of reflections will be controlled by the geometry of façade elements, mullions, fire barriers and other items. Obstructions such as these are likely to improve the sound level difference between the spaces. Absorptive surfaces will also help to minimise reverberant noise build up in the cavity, and hence improve sound insulation.

Oesterle et al[1] have demonstrated that simple rotating internal windows such as those shown below can give a D_w of between 19-28dB depending on window opening angle. They suggest that the calculation of room to room sound level difference can reasonably be approximated by assuming guidance in building services manuals such as CIBSIE and ASHRAE, providing proper consideration for absorption etc are made. Results of a simple test with a narrow façade cavity are demonstrated in the figure below.

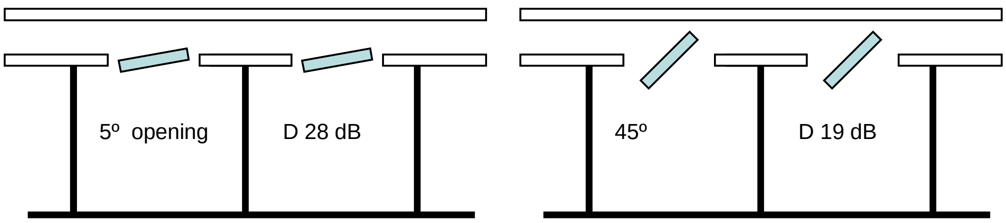


Figure 4: Sound level difference from window opening areas / angles

A final consideration is the level of disturbing noise in the receiver room in relation to the noise from other sources such as services noise. It is at this point that Privacy Factor becomes a useful metric to describe the relative privacy which can be achieved between two spaces.

6.3 Privacy Factors

In this paper, we will discuss privacy using the privacy factors concept. This is based on the concept that privacy is correlated to the sound level difference between two spaces, plus the services noise level within the receiving space, which acts as masking noise. Privacy factor is defined as[5]:

$$PF = NR + D_w$$

In this discussion, we will assume that connected spaces have a constant building services noise level of at least NR30.

6.4 Calculated Privacy Factor

Assuming the window performances demonstrated by Oesterle, and an assumed background noise in a notional office, an assessment of the privacy between two spaces can be calculated. We will consider an open plan office area adjacent to a private office, with sound transmitted via the corridor, wall and window routes, assuming that the windows on the inner facades are either closed, open 5 or 45 degrees. We will also assume external traffic noise ingress does not increase above the services noise upon opening the window.

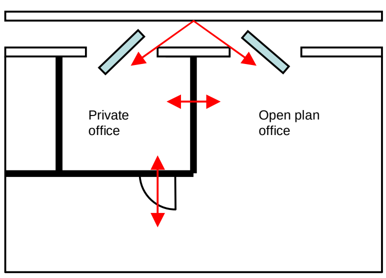


Figure 5: Privacy example – sound transmission routes

The table below demonstrates the privacy factors and privacy ratings afforded by each path.

	Dw	**NR**	**Privacy Factor (Dw+NR)**	**Privacy Rating**	**Normal speech**
Partition	40	35	75	Good	Audible but not intelligible
Corridor	33	35	68	Fair	Audible
Closed Window	50	35	85	Very Good	Just audible
5 degree Open window	28	35	63	Poor	Intelligible
45 degree Open window	19	35	54	Poor	Intelligible

Table 1: Privacy factor example

This demonstrates that the route via the open windows is likely to be poor, resulting in privacy issues, and it is likely that the building design would need further design work, for example adding separating constructions in the cavity, or additional absorptive treatment.

7 MASKING NOISE FROM OPEN WINDOW TRAFFIC NOISE

The examples above consider privacy with a steady state noise level. However, If the windows are opened in a busy urban area, it is likely that ambient noise level in the office will increase from traffic noise. If we were to consider the likely changes in noise level for a street with an ambient noise level of $70dBL_{Aeq1hr}$, incident on a sealed rain screen (Type 1 facade) which is giving a level difference of around D_w8, and an open window which is giving us a reduction of D_w10, very simplistically, we can expect the traffic noise close to the windows of the office floor to be approximately 52 dBL_{Aeq1hr}, or NR45 .

	D_w	**NR**	**Privacy Factor (D_w+NR)**	**Privacy Rating**	**Normal speech**
Closed Window	50	35	85	Very Good	Just Audible
5 degree Open window	28	45	73	Good	Audible
45 degree Open window	19	45	64	Poor	Intelligible

Table 2: Privacy factor examples with masking noise

This demonstrates that there is an obvious trade off between having a good quality sound insulating void, and adding masking noise from traffic to improve privacy issues. Further research is required in this area to gain a fuller understanding of subjective responses to such matters.

8 CASE STUDY

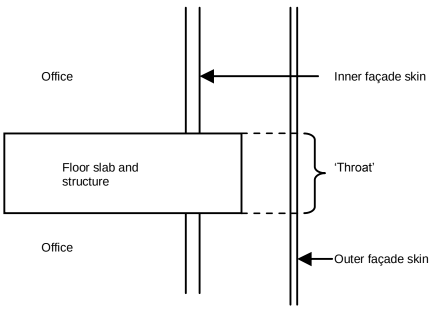
A recent project highlighted the issue of privacy in building with double facades (type 2 identified above). A new high rise office development in the City of London was proposed, which includes high quality office space, with the design team providing a Category A fit out. The building is to be entirely mechanically ventilated.

Although not required for ventilation purposes, the client requested that the inner skin of the façade include openable windows to provide assistance with thermal loading issues. This was identified by the acoustic consultant to have the potential to create issues with reduction in the level of privacy between adjacent rooms. For fire compartmentation reasons, the inner and outer skins of the façade are sealed every three levels, although this does leave a significant number of offices with common voids.

Initially, to evaluate the potential loss of privacy from this arrangement, some simple models were created. As these involved many potential errors, the models were used to gauge whether or not there would be a problem from the arrangement, and what could be done to reduce these effects.

8.1 Estimation of level difference: Duct Calculation

The first verification tool used was to model the noise using a ducted system analogy (this approach was recommended by (1). The base case was taken to be the situation without any absorption, as indicated on the architect’s drawings. The calculation was then repeated with different duct widths and adding absorption, to represent reducing the throat dimensions, and adding absorption to one side of the throat.



	D_w
No absorption – Base case	25
Throat restricted to 300mm	30
Throat restricted to 100mm	42

Figure 6: Schematic diagram of ducted calc and Table 3: Level differences from duct calculation

8.2 Computer Modelling

In addition to this simple calculation, a simplified model of the façade was built using the computer modeling software, ODEON. This software uses a combination of ray tracing and image sources in calculating room acoustic parameters. It was known that this approach would be limited by the diffraction algorithms of the small window surfaces, but it was thought this approach would give an indication into geometrical effects which the ducted model might not take account of.

	D_w
No absorption – Base case	25
With absorption	34
Reduced airway width and absorption	46

Table 4: Level differences predicted by ODEON calculation

The model was built by creating a source room, and 4 identical receiver rooms above, below and either side of the source room. A façade was then built around the open ends of the room by creating a flat surface to encompass one side of the model. No restriction was modeled between the floors, unlike in the ducted calculation, as it was thought these details would become too small to provide accurate results.

As a basic measure of change effects, the results appeared to agree with those produced by the simple duct calculation.

8.3 Scale Model

It was decided that a scale model of part of the façade would be built and tested, to compare the results. Although this method relies on fewer assumptions during the calculation process, the practicalities of taking the measurements meant that there was significant variation in the results. It was anticipated that it would result in more accurate but less precise results.

A 1:10 scale model of the façade was built. It consisted of three 23mm plywood boxes, made of 18mm plywood with 5mm Perspex on the glazed side of the room, enclosed in a Perspex box. The glazed side of the room had panels cut out and mounted on hinges to simulate the windows.

The level difference was measured between the middle room and the rooms immediately above and below it, and averages of these taken. Measurements were taken to establish the drop in sound insulation between rooms with the windows open or shut, and also to evaluate the effectiveness of the proposed added absorption. Results are shown in Table 5.

Windows	**D_w**	**Level of absorption with windows 20° open**	**D_w**
Shut	25	None	19
20˚ open	19	50mm	26
Open	13	100mm	28

Table 5: Results of model tests

These results are much lower than those predicted by either the ODEON model or ducted calculation. It is expected that this is because the way the model has been constructed limits the level difference up to which it is possible to test. This is in the process of being confirmed.

9 SUMMARY

There is great potential for further study into the acoustic effects of sustainable façade design. This paper has identified possible acoustic weaknesses in the design of facades which must be addressed by the design team. Quantifying factors such as privacy and external noise intrusion can be difficult due to exact configurations in façade design, and further investigation is required to determine whether more generic ‘rules of thumb’ can be applied to these situations.

This paper has demonstrated different (applied) modeling approaches for a specific project, and has examined ducted analogies, room acoustic software packages, scale modeling and measurements on real facades. It can be noted that whilst the accuracy of these techniques is limited, a reasonable indication of the effects of these systems can be made, which has informed the design of an on going project.

10 REFERENCES

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11 ACKNOWLEDGEMENTS

The Authors would like to thank Adrian Popplewell and Nick Boulter of Arup Acoustics for their assistance researching this paper.