Investigation of sound insulation for a Supply Air Window – field measurements and occupant response

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ABSTRACT

The Danish Environmental Protection Agency's guideline from 2007 "Noise from roads" introduces noise limits with open windows for certain situations. With a moderate/high outdoor noise level from traffic, railway or industry these noise limits cannot be complied with for regular windows, but requires windows with better sound insulation in open position. The window investigated in this project is a double window construction consisting of an outer part, with a top hung vent in the lower part of the window, and an inner part, with a bottom hung vent in the upper part of the window. The first parts of the project consisted primarily of laboratory measurements investigating the influence of different combinations of e.g. dimensions, opening area and the use of absorbing material. In the second part of the project the window type were installed in 14 flats exposed to approximately 71 dB noise levels from road and railroad traffic. Measurements were performed satisfying the indoor noise limits. The measurements were followed by a questionnaire. The occupants generally responded that the windows allowed them opportunity to have open windows without being especially annoyed by the noise; however other functionalities of the windows were not always acceptable.

Keywords: Sound insulation, open windows, road noise, questionnaire I-INCE Classification of Subjects Number(s): 56.2, 69.1, 32.4, 33, 51.3, 52.3

1. INTRODUCTION

This project focused on acoustical optimization of Supply Air Windows is conducted by DELTA in cooperation with H. S. Hansens Fabrikker A/S.

This paper addresses some of the results achieved in the project. Detailed results are described in (1, 2 and 3) and preliminary results presented in 2011 at Forum Acusticum (4).

The project consists of two parts: The first part is primarily a laboratory study (finished March 2011) supplemented by a literature study and a field measurement. The second part is primarily a questionnaire supplemented by field measurements (finished ultimo 2013).

This paper primarily addresses the results obtained by the questionnaire and fields measurements described in (3).

The project is initiated from (5, 6 and 7). In these guides a new requirement is set that in special situations, where the outdoor noise levels from e.g. road traffic or railroads is high, the indoor noise level in apartments and offices must be under a certain level with open windows, where the opening area is 0.35 m^2. The maximum allowable levels for apartments and offices from road traffic are L_{den} 46 dB and 51 dB respectively. As it is normally not possible to fulfill the requirements with a regular window construction a Supply Air Window would be a solution.

2. The Supply Air Window

The Supply Air Window is in general a double window construction consisting of an outer and an inner part. The window is supplied with at least two sashes which can be opened. In the outer part there is a top hung sash placed in the bottom and in the inner part a bottom hung sash at the top, see Figure 1. In the following the two sashes will be designated "Vents". The window is originally constructed

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with good properties of ventilation and heat insulation in mind.

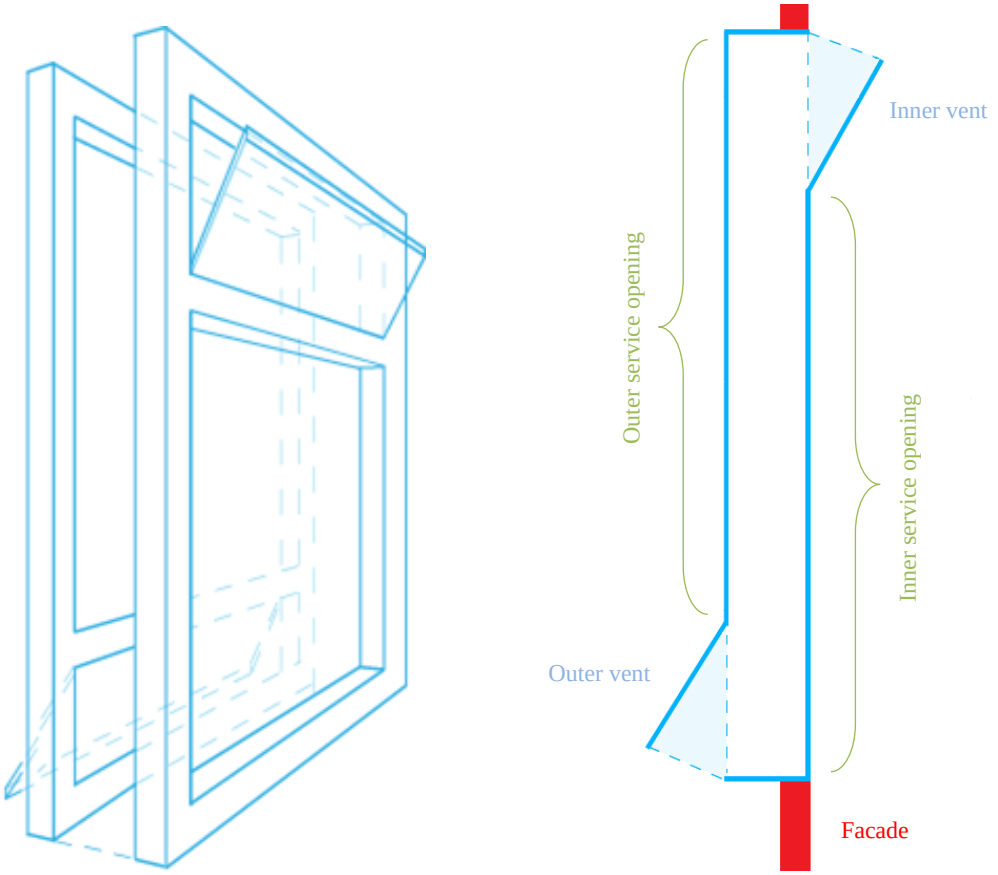

Figure 1 – Left figure: Principle of the Supply Air Window. Right figure: Principle vertical section of the installed Supply Air Window also showing position of vents, service openings and facade

However, the construction also has good acoustic properties, because the noise has to pass through a vertical channel, consisting of the cavity between the two window parts. Thereby a greater damping of the noise is achieved compared to what can be achieved with a normal open window. The sound insulation can be further improved by including sound absorbing material in the cavity. The Supply Air window also has the benefit that when both vents are closed the window has a very high sound insulation, since it now acts as an effective double construction because of the great depth of the cavity. With open vents the achievable sound insulation is more or less independent of the chosen glass units.

2.1 The Supply Air Window used in laboratory test

In the laboratory results were achieved with open vents in the region of R_w = 18 - 30 dB and R_w+C_{tr} = 16 - 24 dB with outer window dimensions (width x height) 1230 mm x 2380 mm. Primary influence on the sound insulation was height of the window, distance to the roof, absorbing material on the roof and amount of absorbing material in the window cavity. With closed vents sound reduction in the region of R_w = 51 - 63 dB and R_w+C_{tr} = 44 - 55 dB were measured. One medium height window (width x height) 1230 mm x 1930 mm were tested in the laboratory and subsequent installed in a building close to heavy traffic, where a field measurement was done yielding comparable results between laboratory and field measurements.

2.2 The Supply Air Window used in Kollektivhuset

The test objects used in the laboratory could be described as temporary solutions or a mock up. For the measurements described in this paper complete prototype Supply Air Windows has been manufactured and installed in a building.

For different practical reasons there has been some changes compared to the laboratory test objects, where the major change is the outer dimensions of the window. The laboratory test objects were installed with inside and outside of the Supply Air Window in line with respectively the inside and

outside surface of the wall. The complete prototype Supply Air Window is installed with the inside part in line with the inside of neighboring windows, meaning that the Supply Air Window can be seen as an "add-on" and not a "build-in" solution, see figure 1 and 4. This however primarily affects the sound insulation with closed vents.

3. Purpose

The purpose of this part of the project is to investigate the function and experience of using the Supply Air Window in real life – both by investigating users' reaction and by field measurements.

4. Description of the site (Kollektivhuset)

To do a real life investigation it was crucial to install the window type in a relevant building – either a new building or a renovated building with a high noise level from preferably road traffic noise on the façade of the building. In the end an apartment building in the northern part of Copenhagen called 'Kollektivhuset' was chosen. Kollektivhuset is a multistory house situated next to a densely populated road and a train junction used by three S-train lines, see figure 2.

Figure 2 – View towards Kollektivhuset including roads and train lines

For Kollektivhuset actually only the two lowest floors of the building were renovated. The use of the lowest floor (1st floor) is nonresidential, where 14 apartments were created on the 2nd floor. For 12 of the apartments the rooms facing the noisy road were identical (half of them with mirrored layout). All 14 apartments had at least one room with installed Supply Air Windows. All 14 apartments also have at least one room not facing the noisy road using regular window types. A typical room facing the noisy road has 3 or 4 non openable window sections and one section with a Supply Air Window as shown in figure 3. For 13 of the apartments two Supply Air Windows were installed in separate rooms, where one of the windows is located in the combined kitchen and living room (hereafter referred to as "combikitchen") and the other in a room, a part of the residents were using as bedroom (hereafter referred to as "bedroom"). For one of the apartments there were two Supply Air Windows in one room (the combikitchen), where for the remaining 13 apartments only one Supply Air Window was located in each room.

Figure 3 – View towards the noisy road with (from the left) two non openable window sections and one Supply Air Window with open vents

The operation of the vents in the Supply Air Window is motorized and controlled by a switch on the wall. The service openings are meant to be used only for emergency and cleaning and are operated manually by handles.

5. Field Measurements

To achieve an impression of the sound insulation of the Supply Air Window mounted in a real building field measurements have been performed.

5.1 Test object

Kollektivhuset is situated next to the densely trafficked Lyngbyvejen in Copenhagen, which also is the southern termination of the motorway to Helsingør. Additionally an elevated train junction used by three S-train lines are also close by, see figure 2. The noise level at the façade at 2nd story level has been calculated to L_{den} = 70-71 dB. Also close to the building Lyngbyvejen is crossing another road which is regulated by traffic lights and in order to have moving traffic, measurements at rush hour has been avoided.

Dimensions of the Supply Air Windows (height x width x depth) are approximately 2.20 m x 0.55 m x 0.32 m. The opening area of the inside vent is approximately 0.29 m^2, while the opening area of the outside vent is approximately 0.25 m^2, and the internal cross section between glass and window bars are approximately 0.16 m^2. The required opening area of 0.35 m^2 can therefore not be fulfilled, which was accepted in this case. In the window cavity are absorbents placed at the frames in the jambs.

Figure 4 – Left figure: View out through the Supply Air Window with both service openings open and vents open. A security glass panel is also visible. Right figure: Two Supply Air Windows seen from the outside next to each other. For both windows the bottom vent is open, where it is only the left Supply Air Window who has an open service opening.

5.2 Measurements

The sound insulation of the windows was measured for two rooms and calculated according to (7, 8). The measurements were performed just before the inhabitants moved in – unfortunately resulting in some disturbance of the measurements due to last minute preparation by workmen.

For each room three measurements were performed, each varying the degree of opening of the vents. The service openings were always closed during measurements. Measurements were performed for two rooms with:

1. The vents fully open
2. The vents half open (compared to 1.)
3. The vents closed.

For the two rooms the weighted sound reduction indexes are shown in table 1 and 2 and the sound reduction index of every one-third octave band are shown graphically in figure 5. The results with vents closed are to some degree influenced by background noise from workmen and should therefore be treated as guiding. With open vents the contribution through the other windows (not Supply Air Windows, see figure 3) can be assumed insignificant and when calculating the sound reduction index the area S is set to the area of the Supply Air Window (1.4 m^2). With closed vents the area of all the windows in the room is used for the area S (8.5 m^2 for the combikitchen and 7.9 m^2 for the bedroom).

Table 1 – Results from field measurements in the combikitchen (Volume 80 m^3)

	R'_w	R'_w+C	R'_w+C_{tr}
Vents fully open (S = 1.4 m^2)	28	26	24
Vents half open (S = 1.4 m^2)	31	30	26
Vents closed (S = 8.5 m^2)	43	41	36

Table 2 – Results from field measurements in the bedroom (Volume 26 m^3)

	R'_w	R'_w+C	R'_w+C_{tr}
Vents fully open (S = 1.4 m^2)	28	27	24
Vents half open (S = 1.4 m^2)	31	30	27
Vents closed (S = 7.9 m^2)	44	42	37

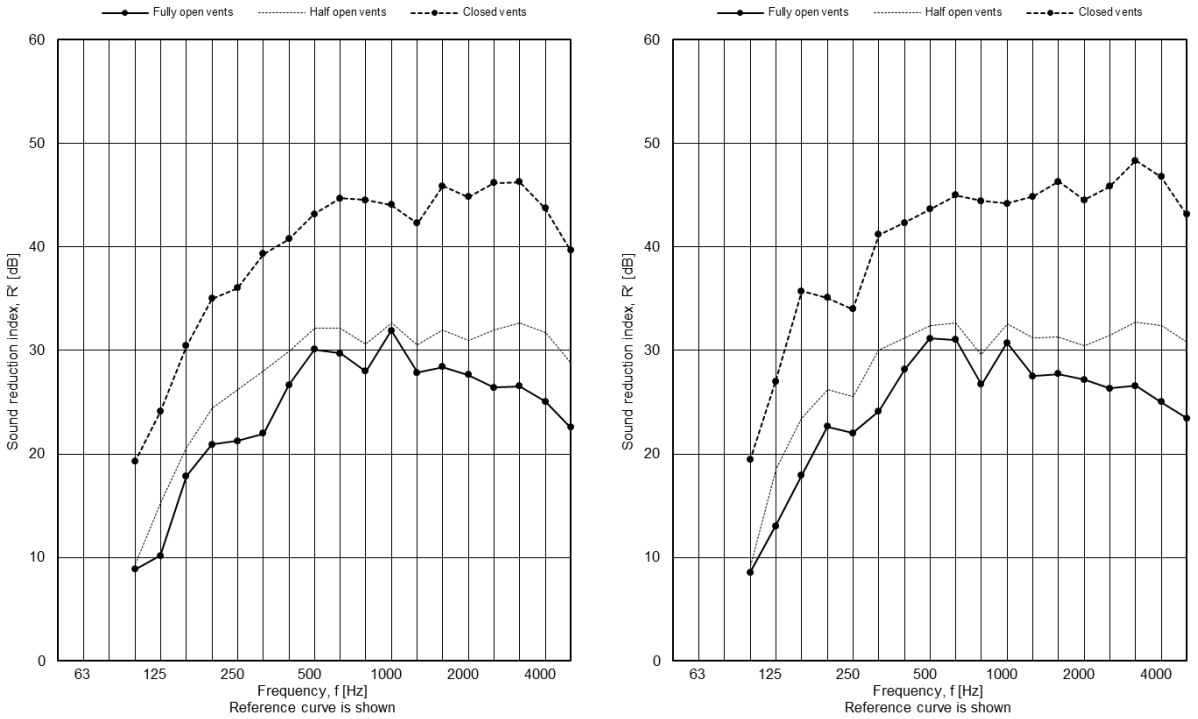

Figure 5 – Sound reduction index for: Left figure: Combikitchen. Right figure: Bedroom

Comparing the results with the expected outcome based on the laboratory results (1, 2) the field measurements show, that the sound reduction is better than expected, however the opening areas of the vents are smaller than the assumed size of 0.35 m^2. It is therefore expected to achieve higher results. In (1) a smaller opening area resulted in an improvement in R_w+C_{tr} = 1-5 dB depending on opening area.

6. Questionnaire

To investigate the opinion of users of the Supply Air Windows a questionnaire has been created.

6.1 Preparation

The questionnaire was prepared by DELTA and focused on general noise annoyance from living close to the densely used road (Lyngbyvejen) in Copenhagen together with operation and daily use of the window type.

The questionnaire use conventional 11-point scales defined by (10), when asking about noise

annoyance and noise sensitivity, in order to make the results comparable to other noise annoyance investigations.

It was chosen to keep responses of the questionnaire anonymous, but the respondent could choose to state the apartment number.

The questionnaire was sent approximately 1 year after the renovation of the flats was completed allow the inhabitants to experience using the Supply Air Windows in all seasons. The questionnaire was written in the Danish language and all responses were received in the Danish language. The total number of questions in the questionnaire was 36.

6.2 Gathering of data

To minimize the influence from an interviewer it was chosen to send the questionnaires by mail and let the respondents respond anonymously. To increase the respond rate it were in the end chosen to supplement the received responses by personal interviews. The final response rate was 57 %.

6.3 Summarized results

The results are based on 8 out of 14 possible responses, where the age of the respondent was 38 year in average (respondents were in the age 22-55 years old) with the gender distribution 3 male and 5 female. Between 1 and 5 persons inhabits each flat, where up to two of these were less than 10 years old.

On average the flats have been inhabited for 9.8 month (minimum 1.5 month and maximum 12 month).

In the following responses from selected questions are presented with both the question and the responses, it should however be noted that the statistical basis is limited. Therefore conclusions regarding users experience with the window type in general should not be deducted. However the result of the questionnaire indicates the opinion of the actual inhabitants of the apartments.

6.3.1 Satisfaction of living in the apartment

Question 13 and 13A are both related to the satisfaction of living in the apartment, see Table 3 and 4. Only two persons would like to move away from the apartment, but any dissatisfaction is not related to traffic noise.

Table 3 – Question 13: Would you like to move away from the apartment?

Yes	No	Don’t know
2	3	3

Table 4 – Question 13A: If yes, - would one of the major reasons be related to traffic noise from the road?

Yes	No
0	8

6.3.2 Operation and cleaning of the Supply Air Windows

Question 17 and 18 are both related to the operation and cleaning of the Supply Air Windows, see Table 5. On average the respondents experience that handling the Supply Air Window is easy, however one respondent comments that the motorized opening of the vents is too slow. Oppositely cleaning of the Supply Air Window is clearly difficult to the respondents. In question 21 the respondents are asked about their general opinion of the Supply Air Window. One of the responses was: “*when you cannot open them entirely it is a challenge/impossible to clean the windows. But the noise level is clearly reduced*”.

Table 5 – Question 17 and 18 – related to handling and cleaning of the Supply Air Window

	Very difficult 0	2	4	6	8	Very easy 10
Question 17: How do you experience handling the Supply Air Window					Average 7.9	
Question 18: How do you experience cleaning of the Supply Air Window and internal cavity?	Average 1.6					

6.3.3 **Use of the Supply Air Window when fresh air is needed**

Question 26 is related to how the Supply Air Window is used when fresh air is needed, see Table 6. The unambiguous response from all answers is that the windows are not used as intended, but that instead an opening combination of vents and service openings always is used.

Table 6 – Question 26: How do use the Supply Air Window when you want fresh air?

Only opens vents	Only opens service opening	Combination of vents and service opening
0	0	8

6.3.4 **Noise reduced effect of the Supply Air Window**

Question 27 is related to the noise reduced effect of the Supply Air Windows, see Table 7. The majority of the respondents feel that the Supply Air Windows provides them the opportunity of open windows without being especially annoyed by traffic noise.

Table 7 – Question 27: Do you feel that the Supply Air Window provides you the possibility of open windows without considerable annoyance from the noise from the road?

Yes	No	Don't know
5	2	1

6.3.5 **Does the Supply Air Window provide sufficient amount of fresh air**

Question 33 is related to whether the Supply Air Window provides a sufficient amount of fresh air in the summer, see Table 8. The response is "no" for all respondents, and it is assumed that even with both vents and service opened the amount of fresh air is not sufficient.

Table 8 – Question 33: Does the Supply Air Window provide sufficient amount of fresh air in the summer when opened?

Yes	No
0	8

6.3.6 **Sufficient temperature reduction with vents in the Supply Air Window?**

Question 34 and 35 is related to whether the Supply Air Window is sufficient to reduce the temperature of the room, see Table 9 and 10. From the combined answers it appears that the majority of the respondents has experienced that the temperature cannot be reduced sufficiently by using the vents alone. The temperature is to some degree reduced sufficiently by also using the service openings, which supports the findings in question 33.

Table 9 – Question 34: Have you experienced that you cannot reduce the temperature sufficient by opening the vents in the Supply Air Window?

Yes	No	Sometimes
6	1	1

Table 10 – Question 35: If yes (Question 34), - can the temperature be reduced sufficiently by opening the service openings in the Supply Air Window?

Yes	No	Sometimes
2	3	3

7. CONCLUSIONS

A questionnaire has been executed in order to investigate occupant responses of function and handling of the noise reducing Supply Air Windows mounted in the apartments at the 2nd floor in Kollektivhuset in Copenhagen. All respondents answered that the Supply Air Window gives them the opportunity to have open windows without being especially annoyed by traffic noise from the densely trafficked road (Lyngbyvejen) close to the building.

The respondents answers that the windows are easy to operate but difficult to clean.

All respondents answers that they use a combination of vents and service opening when they want fresh air in the apartment, and that the reason for this is that there is not enough supply of fresh air through the vents alone. The windows are therefore not used as intended, and the expected effect of installing noise reduced open windows are compromised owing to the inadequate dimensioning of the Supply Air Window compared to an adequate amount of fresh air in the apartment. The opening areas of the vents are also smaller than the required 0.35 m^2.

Additionally sound insulation measurements have been performed prior to the inhabitants moved into the flats. The measurements show that the indoor noise level with open windows (open vents) are less than the required L_{den} = 46 dB, and also that the sound insulation were better than expected which to some degree also can be explained by smaller opening areas of the vent than the required 0.35 m^2.

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