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The design of sound insulation measures for dwellings around Amsterdam Airport Schiphol

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Abstract [132] In the surroundings of Amsterdam Airport Schiphol approximately 14000 dwellings are being sound insulated. Half of the dwellings will receive low level insulation ranging from 20 to 27 dB(A), half will receive high level insulation ranging from 30 to 40 dB(A). The measures vary from improving airtightness and ventilation silencers to heavy provisions to roofs and windows or even replacement of dormers. Especially the large number of dwellings with relatively low required sound insulation level emphasizes the importance of an efficient engineering process. Peutz was involved in the methodology of the acoustical design of both the low and the high level sound insulation. To reduce engineering and insulation costs acoustic design methods have been developed and implemented in computer programs, based on optimization of costs. Special attention has been paid to the sound reduction by the building itself, depending on the angle of incidence. The quality control by laboratory measurements of the sound insulation of building elements was essential for the acoustical result of the project.

1 REQUIREMENTS

Since in the area around Amsterdam Schiphol Airport the sound exposure by aircraft is exceeding Dutch regulations limits, sound insulation has to be provided to the existing dwellings and apartment buildings within this area. The sound insulation has to be provided by the Dutch government but is paid indirectly by the airlines landing at Schiphol. There are two area's involved:

1. The so called Ke-area that has the highest level of required sound insulation. The sound exposure is based on maximum sound pressure levels and the number of events. Sound insulation is based on reduction of annoyance and is required for all rooms that are intended for living, sleeping and so

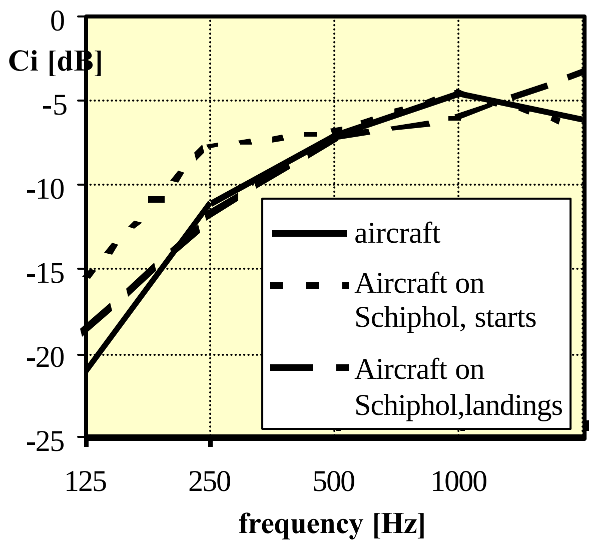


Figure 1: *Reference spectra used for aircraft noise*

on. The required sound insulation depends on the sound exposure and varies from 30 to 40 dB(A) with steps of 0.5 or 1 dBA(A). The spectrum is a general standardised spectrum for aircraft noise.

2. The so called L_{Aeq}-area that is at the outer side of the Ke-area and has a fairly low level of required sound insulation. The sound exposure is the night average equivalent sound pressure level. The inside sound exposure level should not exceed L_{Aeq}= 26 dB(A). The requirements are based on reduction of sleep disturbance and are applied only for bedrooms. The required sound insulation also depends on outside sound exposure and varies from 20 to 27 dB(A). The spectrum depends on the types of aircraft and the procedure (take off or landing). For Airport Schiphol two standard spectra have been determined: for start and landings. The spectra are shown in figure 1.

The inside sound exposure level L_{Aeq} is calculated from:

$$L_{Aeq} = 10 \log \{10^{L_{Aeq,in,starts}/10} + 10^{L_{Aeq,in,landings}/10}\} \qquad (1)$$

$$L_{Aeq,in,starts} = L_{Aeq,out,starts} - G_{A,starts}$$

$$L_{Aeq,in,landings} = L_{Aeq,out,landings} - G_{A,landings}$$

where:

$L_{Aeq,in,starts}$ = the L_{Aeq} sound exposure in dB(A) inside a bedroom due to take off;
$L_{Aeq,out,starts}$ = the L_{Aeq} sound exposure in dB(A) outside due to take off;
$G_{A,starts}$ = the sound reduction of the facade in dB(A) for the starts spectrum;
$L_{Aeq,in,landings}$ = the L_{Aeq} sound exposure in dB(A) inside a bedroom due to landing;
$L_{Aeq,out,landings}$ = the L_{Aeq} sound exposure in dB(A) outside due to landing;
$G_{A,landings}$ = the sound reduction of the facade in dB(A) for the landings spectrum;

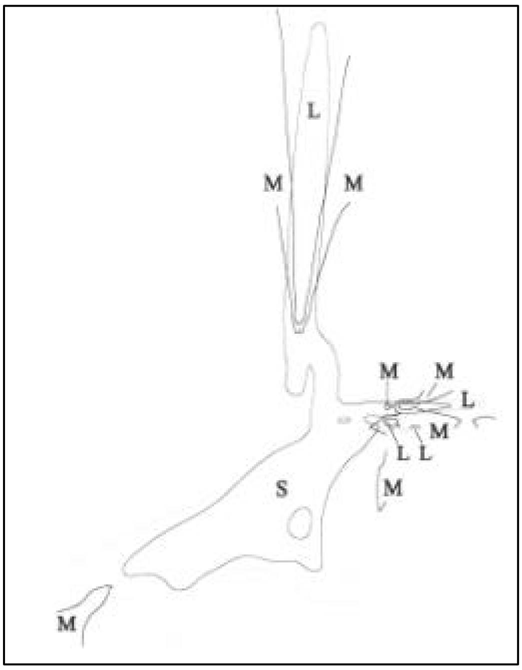
In 2003 the fifth runway of Schiphol was put into use. The sound insulation program however started in 1997 so the sound exposure of both the 4 runway system as the 5 runway system had to be taken into account.

2 METHOD FOR THE L_{AEQ} AREA

The conventional way of the engineering would include the following steps:
- a first inspection of the dwelling, taking measures, taking pictures
- making (simple) drawings of the dwelling
- calculation of the necessary acoustical provisions by the acoustical consultant
- working up the drawings to include the acoustical provisions
- a second inspection of the dwelling for verification and a meeting with the residents explaining the measures
- contract with the residents
- a third inspection of the dwelling with the contractor

This way of engineering might be needed for the high sound insulation where radical measures are needed. For the low insulation however the most common measures will be improving the air tightness and ventilation silencers. For most of the houses it is not necessary to replace the glazing. The steps above cost a lot more than the actual provisions. So there has been an urge to simplify the procedure and research has been done to have a simplified acoustical engineering. Basic idea was to have one or two standards and just to verify (using graphs or so) weather the sound insulation would be sufficient for a specific room. Looking at equation (1) a first step to simplify the calculation would be to only apply one spectrum. Figure 2 shows the L_{Aeq} contours of Schiphol

(5 runway system) with the areas where starts are dominating (S), Landings (L) or a combination (M). For the latter case the starts spectrum can be applied, since that is the most critical spectrum as for sound insulation.



Figuur 2. *Dominating procedures for the 5 runway system. L=landings, S=starts, M=mix. The 26* L_{Aeq}*-contour is shown and the differential contours (S: s-l > 3dB; M: -3dB < s-l < 3dB; L: s-l < -3dB)*

The sound reduction of the façade is calculated from:

$$G_{i,j} = R_{i,j} - 3 + C_{L,j} + 10 \log V/6T_0S_j \text{ [dB]} \qquad (2)$$

where:

- $R_{i,j}$ = the sound insulation of facade j for octave band i;
- $C_{L,j}$ = additional sound reduction due to the shading of the facade j (see chapter 3);
- V = volume of the room, in m³;
- T_0 = standard reverberation time (0.5 s);
- S_j = surface area of facade j in m².

Facade j consists of surfaces (brick walls, glazing) , slits and separate elements (e.g. ventilation openings).The sound insulation $R_{i,j}$ of facade j is calculated from:

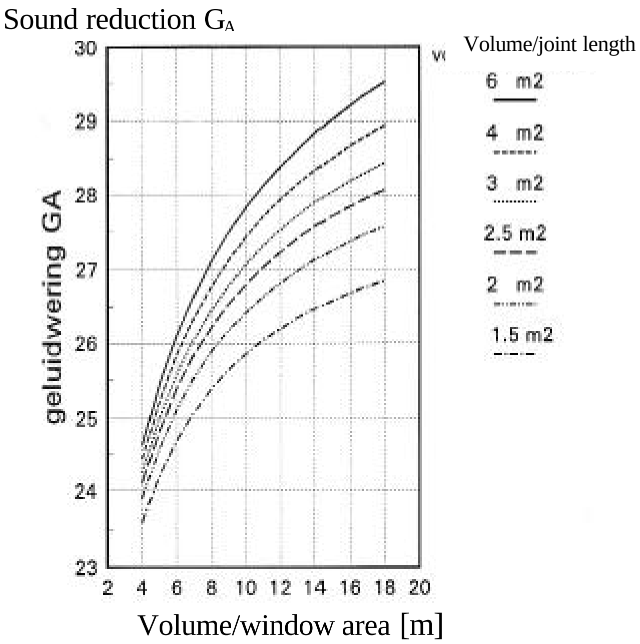
$$R_{i,j} = -10 \log \frac{1}{S_j}\left[\sum_{e=1}^{n} S_e \bullet 10^{-R_{i,e}/10} + \Sigma\, l_k \bullet k + A_0 \bullet 10^{-D_{ne,i}/10}\right] \text{[dB]} \qquad (3)$$

where:

- S_j = surface area of facade j [m²];
- S_e = area of surface e [m²];
- n = number of surfaces for facade j;
- $R_{i,e}$ = sound insulation of surface e for octave band i [dB];
- l_k = length of openable and fixed joints [m];
- k = acoustical quality of the joint per meter. For good quality single (openable) joints this will be $3{\cdot}10^{-4}$, for good quality double joints about 10^{-5};
- $D_{ne,i}$ = element-normalised level difference (for a 10 m² reference area) of a ventilation grill;
- A_o = reference absorption area: 10 m².

For this calculation there are a number of parameters that are influenced by geometry and a number that have to do with the acoustical quality of the different elements. By making reasonable assumptions as for the quality and measuring the geometrical factors it should be possible to make an easy and sufficiently accurate estimate of the sound reduction. So that means:

- measuring S_j , l_k, and V;
- assumption for $R_{i,e}$ of existing surfaces;
- the quality of new elements such as joints and ventilation silencers is known
- assumption for the shading $C_{L,j}$ which is mostly 1 dB or more (see also chapter 3).



The quality of relatively simple joint gaskets is measured in the laboratory, for different openings of the joint. From that a minimum quality is fixed of 26 dB(A). From this data graphs are made of the sound reduction depending of the ratio volume/joint length and the ratio volume/window area, see figure 3. This graph is for the combination chink filling and a specific ventilation silencer. Other graphs are made for attic rooms where provisions to the roof might be needed.

Figure 3. *Graph for the verification of the sound reduction*

The method is verified with measurements of 26 rooms in 8 dwellings (see also [1]). From these measurements the following conclusions were drawn:

- In a number of cases the calculated sound insulation was not reached because of specific problems (such as leakage at the joint between window frame and brick wall or by lightweight panels that were not noticed during inspection)
- The practical use of the graphs was not so good
- Some minor adjustments were needed in the assumed sound insulation of existing constructions

To improve the method it was decided not to use graphs but a computer calculation on a laptop, having also the advantage of a more detailed calculation (less assumptions).

3 SHADING BY THE FACADE

The sound exposure is calculated for a free field situation. The sound exposure on the facade in the L_{Aeq}-area is almost equal to this free field sound exposure if there is free sight from the source to the facade. If the source is shaded by the building (angle to the normal on the facade more than 90 degrees) however the sound exposure on the facade is reduced. For a dwelling in the middle of the range or flight paths the average (equivalent) reduction due to this shading is about 2.5 – 3 dB. At the edge of the range of flight paths there is no reduction for the facade facing the flight paths, since it sees all the air craft, but a high reduction for the opposite facade since this one is not seeing any aircraft (see figure 4). Measurements are made of the angle dependant sound reduction of the facade, see [1]. For all positions around Schiphol and 8 possible orientations of the facade the reduction to this shading effect was calculated by calculating the total sound exposure with and without integrating the angle

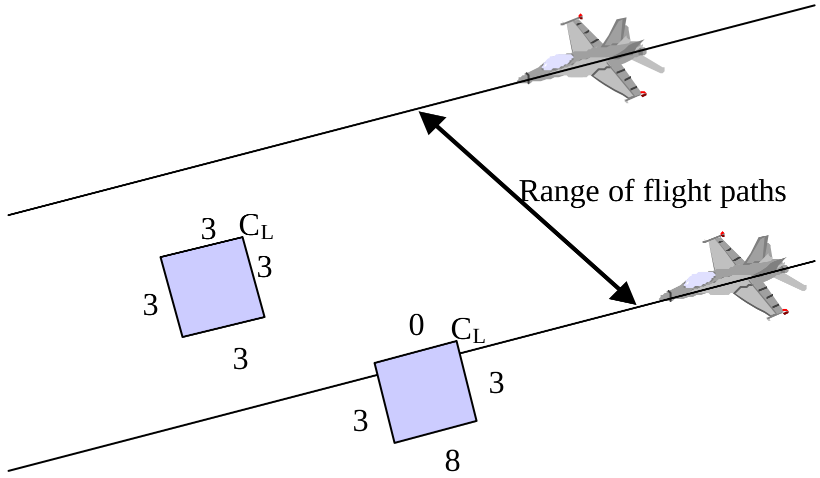


Figure 4. *The reduction of the sound exposure on the facade, due shading by the building itself, depending on the orientation and the location of the dwelling within the range of flight paths.*

dependant sound reduction. From this a database was established with sound reduction by shading $C_{L,j}$. The database is used in the computer program described in chapter 2.
The calculation of the sound exposure in the Ke-area with the high sound insulation levels is different from the L_{Aeq}-area in the sense that sound exposure is not based on equivalent sound pressure levels but on maximum SPL. The shading is also calculated but just for single positions of the plane.

Figure 5 shows a possible position of the plane and the resulting shading effect for that position. For rooms with more than one facade the calculation of the sound insulation has to be performed for all four possible positions of the plane and the sound insulation is the lowest result from these four. The reduction by shading is only applied for facades. For flat and sloping roofs no reduction is applied.
Important is that the reduction of the facade can also be measured separately for the different facades if a room has more than one. Otherwise it would not be possible to apply different reduction due to shading to different facades and thus verifying the total sound reduction. Measurement methods were adopted for that purpose. The most important thing to consider is cross talk to the other facade that is not intended to contribute to the transmission loss.

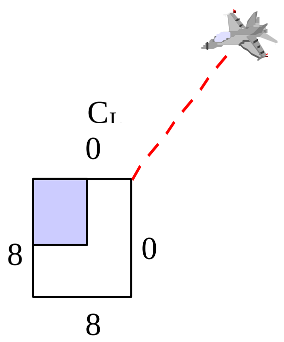


Figure 5. *Shading with a single position of the plane*

4 METHOD FOR THE Ke AREA

In the L_{Aeq}-area it was possible, due to the low level of insulation required, to a certain extend maintain building elements such as glazing and roof construction. For the L_{Aeq} just a few combinations of provisions is sufficient. In the Ke-area the required sound insulation is much higher (30-40 dB(A)) which means that all building elements have to be considered and all light weighted elements have to be improved or replaced. Since these elements have to be improved anyway, the acoustical quality is hardly dependent on existing construction but only on the new constructions. For each facade element (such as glazing, flat roof, sloping roof, chink filling, ventilation, doors) an optimum selection has to be made. It is not logical anymore to have fixed combinations of

provisions. The question however is how to determine for each element the best choice (for roof construction e.g. adding one gypsum board, or two or three, on an air gap of 100 mm or 150 mm and so on).
A logical choice would be to select that combination of provisions that will require the lowest total investment. The selection procedure can be described by the following example of a room with a lightweight roof of 20 m^2 and a window of 4 m^2. The total sound reduction is only depending on those two elements.

roof\glass	30	33	36
37	32	33	34
40	33	35	36
43	34	36	38

Table 1. *Example of the calculated sound reduction depending on the sound insulation of window and roof (in dB(A)).*

roof\glass	30	33	36
37	--	--	+
40	--	+	+
43	+	+	+

Table 2. *Combinations of provisions with which the requirement of 34 dB(A) can be fulfilled*

roof\glass	€ 60/m^2	€ 65/m^2	€ 90/m^2
€ 50/m^2			€ 1360
€ 57/m^2		€ 1400	€ 1500
€ 63/m^2	€ 1500	€ 1520	€ 1620

Table 3. *Insulation costs for different combinations of provisions*.

For each element e.g. 3 levels of acoustical quality can be introduced: for the glazing 30, 33 or 36 dB(A) and for the roof 37, 40 or 43 dB(A). Table 1 gives the total sound reduction resulting from the possible combinations of the window and the roof. If in this specific case the required sound reduction is 34 dB(A), the combinations given in table 2 will fulfil these requirements. The question is which of these combinations has the lowest costs. Because the costs of all constructions are known (€ per m^2) the total investment can be calculated for all combinations that meet the sound reduction requirement (table 3). The cheapest combination can be selected (marked). In this case this is the 36 dB(A) glass in conjunction with the 37 dB(A) roof. This way the economic optimum solution can be selected.
In the case of two building elements (roof and window) this leads to a two-dimensional matrix. In reality there can be much more building elements. The following objects are considered as separate building elements: fixed glazing, glazing in openable windows, doors, openable joints, fixed joints, light weight facade elements, sloping roof, flat roof, flat roof of a dormer, dormers side walls, skylight, ventilation opening and brick wall. This results in a 12-dimensional matrix with the number of combination possibilities depending of the number of provisions for each element. In this there are over 2 million combination possibilities. Simplifications are applied, e.g. always select the same glass for the fixed and openable window (except for the very high sound insulation), always use double chink filling, separation in the tables used for middle and high sound insulation.

The method is implemented in a computer program that is used on site to enter the geometry and calculate the acoustical measures. Basically this process does not require an acoustical consultant. The cost estimates are also being used to assess the costs per dwelling.
Not only the cheapest result is presented but also the next two, so there are some possibilities to tune the measures of adjacent rooms. It is also possible to enter fixed choices for specific elements.
The calculation of ventilation silencers is in two steps: the first determining the quality level, the second selecting a specific product, based on available dimensions and costs.
Additionally the program has the possibility to fill in checklists concerning special situations which might be acoustically relevant.

5 QUALITY CONTROL

Especially since the engineering process was to a great extent done without an acoustical consultant it is important that a good quality control is applied in all the steps of the engineering process. Some of the elements of the acoustical quality control are:

- Prescribing the minimum sound insulation of the construction elements
- Verification of the sound insulation of the constructions to be applied in the laboratory (by the contractor)
- A margin between laboratory results and calculation values, depending of the type of construction and the practical difficulties that can be expected
- The checklists mentioned above

Especially the verification in the laboratory was considered unusual. For a number of constructions these measurements have led to adjustments to the constructions and therefore these laboratory measurements have contributed to the final result. Furthermore this way the development of better or smarter constructions is stimulated.

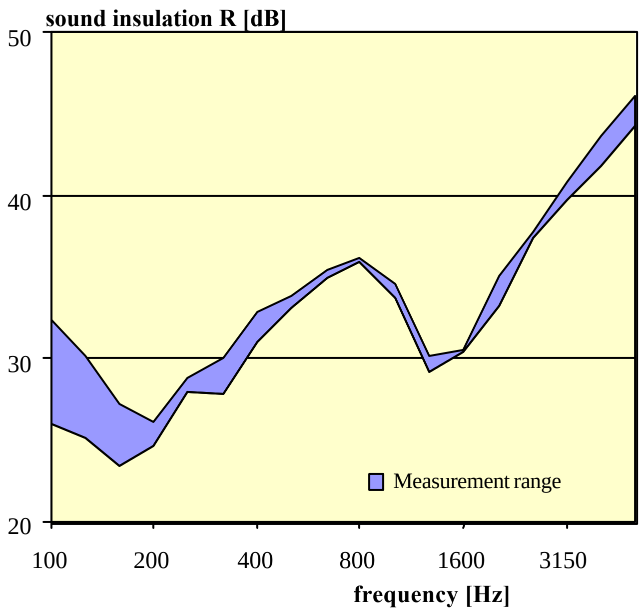


Figure 6. *Measurement range of the sound insulation of a 10 mm glass pane, sealed, measured in three laboratories (Peutz, Tue, TPD).*

One of the elements that is tested in the laboratory is the glazing, which is a very important element because it mostly has the largest contribution to the overall sound transmission. Data coming from different labs showed large deviations. Not all data was based on the 1995 version of ISO 140-3 and non standardised mounting methods were used. It was decided that all glazing should be tested in one laboratory, of Peutz Netherlands (which has an accreditation for sound insulation measurements). The repeatability is 0.13 dB(A). The absolute values are verified by a small round robin on a standard 10 mm pane, in which three Dutch laboratories participated. The results are shown in figure 6. The sound insulation varies form 26.9 to 27.7 dB(A), with the same mounting in all laboratories.

From the measurements of the sound insulation of the different glazing for the Schiphol project it was concluded that the original specifications of the suppliers could not be met and eventually the following glass panes given in table 4 were selected:

Sound insulation $R_{A,}$(standard aircraft noise)			composition	
Calculation value	Laboratory requirement	Laboratory measurement	glass-gap-glass	filling
29.0	31.0	31.8	4-15-6	air
31.5	33.5	35.0	4-24-6	sf6
34.0	36.0	37.0	5-24-8	sf6
35.5	37.5	38.3	6-20-66.1	Ar
37.0	39.0	39.8	12-24-44.2	sf6
39.0	41.0	42.7	10-24-5.1.5	sf6
41.0	43.0	43.8	86.2-24-44.2	Ar
44.0	46.0	45.8	86.2-24-64.2	Ar

Table 4. *Selected window panes based on laboratory measurements*.

6 CONCLUSION

In the preceding the methods are described for the acoustical design of both the low and high sound insulation around Amsterdam Airport Schiphol. For both area's it was proved possible to calculate the necessary acoustical measures with a computer program. Special attention has been paid to the reduction of sound exposure due to the shading of the facade. To reduce insulation costs a cost optimisation program is developed and implemented. The acoustical and construction engineering is integrated, thus enabling lower engineering costs and reduced handling time.
Setting requirements for the sound insulation of building elements in the building contract and verifying the sound insulation in the laboratory has greatly improved the quality of the final result.

REFERENCES

[1] M.L.S.Vercammen, "Het ontwerp van geluidwerende voorzieningen bij het geluidisolatieproject Schiphol", in *NAG journaal* nr 162, pp 13-35, 2002. (in Dutch).