



Aircraft noise annoyance and residents' acceptance and use of sound proof windows and ventilation systems

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Residents of Raunheim (a town with 15,000 inhabitants, ca. 8 km west of Frankfurt Airport) are highly exposed to aircraft noise, in particular in case of east flight operation mode (LAeq,16h > 60 to 70 dB(A) for operation mode east, LAeq,16h > 50 to 60 dB(A) for operation mode west). The whole city is included in the night protection zone and thus benefits from the airports noise protection program. That is, house owners are entitled to benefit from a 100% funding of sound proof windows combined with ventilation systems in bedrooms by the airport operator Fraport AG. To assess the residents' acceptance and use of sound proof windows and ventilators as well as the associations with aircraft noise annoyance, sleep disturbances, and the perceived room climate a telephone survey with 765 residents in Raunheim was conducted. The results indicate that sleeping with usually closed windows and active ventilators in bedrooms is associated with negative evaluation of the indoor climate, elevated aircraft noise annoyance, and reported sleep disturbances. This suggests that these insulation measures cannot replace operational measures to reduce aircraft noise such as night flight limitations, optimized take-offs, and landing procedures.

1 INTRODUCTION

Many studies have shown the aversive effects of aircraft noise on human beings, such as noise annoyance, sleep disturbances, cognitive impairment of children, or cardiovascular diseases¹. In 2011, the World Health Organization presented a report on the burden of disease from environmental noise in terms of disability-adjusted life-years (DALYs) for each of these outcomes². In particular, aircraft noise at night-time has been identified to be harmful for human's health^{3,4}.

Noise abatement measures at home in terms of façade insulation (insulation of the wall, sound proof windows alone or combined with ventilation systems) provide a considerable reduction in indoor sound levels. With regard to the efficacy of these measures in reducing indoor noise effects (annoyance, disturbances), results are ambiguous⁵⁻⁷.

Noteworthy for the evaluation of the benefit of sound proof windows are the results of European studies indicating that in warmer seasons even in noisy areas people usually have their bedroom windows open during the night⁸⁻¹⁰. There is some evidence that, at the same noise level,

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residents with predominantly closed bedroom windows at night-time in warmer seasons report higher noise annoyance and disturbances indoors than those persons that have their bedroom window predominantly open or partially open⁸. It is assumed that closing the bedroom window in warmer seasons is mainly because of the external noise and thus indicates a behavior to cope with it. As people at least in Europe generally seem to prefer open or tilted windows it is likely that being forced to close the windows is in itself annoying or a noise-related disturbance¹¹. On the one hand, the environmental noise can be substantially reduced indoors by closing the windows, on the other hand this may be in conflict with (perceived) indoor climate (temperature, air humidity, air quality), which is known as an important dwelling attribute¹².

Thus, noise insulation programs including sound proof windows and ventilation systems may be less efficient in terms of reduction of aversive noise effects (annoyance, disturbances) than expected from the indoor sound level reduction these measures provide. In addition, such insulation programs do not protect people outdoors, i.e. on the balcony, in the garden, or in local recreational areas. For residents in the vicinity of airports, for example, this would mean that insulation programs can be regarded as a last resort to reduce aircraft noise and that other noise control measures such as noise optimized flight procedures, temporal (nocturnal) flight limitations, or noise reduction from the source (single plane) still should be preferably considered as measures of aircraft noise control.

Against the background of these considerations the municipality of Raunheim, a town 8 kilometer (5 miles) west of Frankfurt Airport, decided to commission two studies: (1) A survey on the citizens' acceptance and use of sound proof windows and ventilation systems offered by the airport operator Fraport AG, (2) a simulation study on modeled indoor climate and thermal comfort for different house types, years of construction, and scenarios with/without implemented aircraft noise insulation measures (sound proof windows, ventilation systems).

In this contribution the main results of the survey (1) are presented. Key issues of the survey are:

- number of installed sound proof windows and ventilation systems in the dwellings and the frequency of their use;
- the reasons to shut or not to shut sound proof windows and activate the ventilation systems in the bedroom during the night;
- the attitudes towards insulation measures;
- relationships between the use and acceptance of sound proof windows and ventilation systems, perceived indoor climate, aircraft noise annoyance, sleep disturbances and sleep restfulness.

2 METHODS

2.1 Study area

The survey's study area is the city of Raunheim. Located near to Frankfurt Airport the residents of Raunheim are highly exposed to aircraft noise, in particular in case of east flight operation mode ($L_{Aeq,16h} > 60$ to 70 dB(A) for operation mode east, $L_{Aeq,16h} > 50$ to 60 dB(A) for operation mode west). The whole city is included in the night protection zone and thus benefit from the airport's noise protection program. That is, house owners are entitled to benefit from a 100% funding of sound proof windows partly combined with ventilator systems in bedrooms by the airport operator Fraport AG.

2.2 Questionnaire

The questionnaire used in the survey includes the following topics:

- *Residential situation*: length of residence, residential satisfaction (dwelling, residential area), type of dwelling, ownership.
- *Sleep quality, noise annoyance*: restfulness of sleep, aircraft noise annoyance (total, daytime, night-time), sleep disturbances due to aircraft noise, road traffic noise annoyance, annoyance due to other noise sources.
- *Windows, airing*: Type of windows in living room and bedroom, predominant position of windows in warmer seasons in bedroom, reasons for predominantly closed windows, funding of existing sound proof windows
- *Bedroom, insulation in bedroom, windows*: position of bedroom (floor, geographic direction, existence and use of ventilation system, attitudes towards insulation measures (sound proof window, ventilation system), perceived indoor climate (temperature, air humidity, air quality, indoor climate in total), usual number of persons in bedroom at night-time
- *Open question*: suggestions of aircraft noise control measures
- *Socio-demographical factors*: Gender, age, migration background, occupation (professional training, employment, position, shift work, job associated with/dependent on the airport), income

Most aspects of the questionnaire were assessed with single items. For the assessment of annoyance the five-point scale according to ISO/TS 15666¹³ was used. The sleep disturbance due to aircraft noise was assessed with three items referring to disturbances when falling asleep, sleeping through the night, and sleeping in the early morning (Cronbach's alpha $\alpha = .84$). A five-point scale similar to the annoyance scale was used for this assessment.

2.3 Procedure

Computer-aided telephone interviews (CATI interviews) were carried out with citizens of Raunheim sampled randomly on the base of official housing stock and telephone data base. Before the start of the interview all sampled households were informed by the municipality about the study in written form and asked for their participation. Within the households the interviewed persons were selected by random (last birthday method). The interviews took place in October and November 2010, the mean interview duration was 15 minutes.

3 RESULTS

3.1 Sample

765 persons (393 women, 372 men) from 18 to 92 years (64% house owners, 36% tenants) were interviewed. The response rate was 56%. 48% of the participants live in apartment buildings, 6% in mid-terrace houses, 8% in end-terrace or semidetached houses, and 37% in detached houses.

3.2 Window types in the bedroom and participation in noise protection program

53% of the 765 participants have triple glazing, 42% double glazing and 2% single glazing windows (3% don't know). 409 (54%) of the interviewees (65% of the house owners, 33% of the tenants) stated that the airport operator had funded the windows (72% triple glazing, 28% double glazing windows) as part of the airport noise protection program.

486 (64%) of all interviewed persons possess a ventilation system in their bedroom, 309 of them (64%) got this ventilation system in addition to the sound proof windows funded by the airport operator.

Taken together, of all those participants with insulation in their bedroom 76% of the installations were funded by the airport operator.

3.3 Window position and use of ventilation system in the bedroom

Most of the participants have their bedroom window usually open or partially open in warmer seasons (62%), even those with sound proof windows funded by the airport operator (60%) (Table 1).

252 Persons answered to the open question, why they have the bedroom window predominantly closed in warmer seasons. According to these responses the main reason for predominant closed windows is aircraft noise (85% of the responses), followed by not noise-related reasons (12%; mainly weather, security, insect protection), road traffic noise (2%), and noise from other sources (1%).

248 participants (51%) from the 486 households with a ventilation system in the bedroom reported to usually have the ventilation system activated at night-time (Table 2). That is, almost half of the participants do not use the ventilation system in the bedroom. Even in those households that are taking part in Frankfurt airport's noise insulation program, 42% of the respondents do not use the ventilation system at night-time.

According to 244 responses of 225 persons (multiple answers were possible) the main reasons not to use the ventilation system in the bedroom at night-time are:

- 39% of the responses: noise from the ventilator, noise from outside
- 17% of the responses: use of alternatives to the ventilator (open windows, open bedroom door, airing at daytime)
- 15% of the responses: indoor climate
- 10% of the responses: not necessary, not disturbed/annoyed by environmental noise
- 9% of the responses: quality of ventilator, technical problems, usability
- 7% of the responses: costs for acquisition, user costs
- 2% of the responses: health-related reasons (headache, bacteria)
- 3% others

3.4 Perceived indoor climate in bedroom

The perceived indoor climate in the bedroom in the early morning was assessed with the following four items:

- When getting up the room temperature in the bedroom is usually ...
much too warm – too warm – just pleasant – too cold – much too cold
- When getting up the air humidity in the bedroom is usually
much too dry – too dry – just right – too humid – much too humid

- When getting up the air quality in the bedroom is usually ...
very moldy – moldy – neutral – cool – very cool
- All in all, when getting up the indoor climate in the bedroom is ...
not – a little – moderately – rather – very pleasant

Judgments on the five-point bipolar scales for room temperature, humidity, and air quality were transformed on a three-point scale with the categories (1) pleasant, neutral (2) unpleasant, (3) very unpleasant (Figure 1).

Figure 1 shows that the pleasantness of the room temperature, air humidity and air quality in the bedroom correspond with the perceived pleasantness of the indoor climate in the bedroom in total indicating that the subjectively assessed indoor climate is an adequate indicator of perceived physical characteristics of the climate in the bedroom.

The respondents with predominantly open or partially open bedroom windows in warmer seasons judged the indoor climate as being more pleasant than those respondents with predominantly closed windows ($F_{[2,711]} = 10.2$; $p = .002$). In accordance with this, the participants, which usually do not have the ventilations system activated in the bedroom during night's sleep, report a higher pleasantness of indoor climate than those that usually have the ventilation system activated ($F_{[2,711]} = 19.6$; $p = .000$) (Figure 2).

3.5 Aircraft noise reactions and sleep-restfulness

Table 3 shows the relationship between the window position and use of the ventilation system, perceived indoor climate and aircraft noise annoyance, aircraft noise-related sleep disturbances, and sleep-restfulness.

In summary, the results indicate:

- Participants with usually closed bedroom windows in warmer seasons are more annoyed and sleep disturbed by aircraft noise and perceive the indoor climate in the bedroom as less pleasant than respondents which predominantly have their bedroom window half-open or open at night. The – at first sight – corresponding relationship between window position and sleep-restfulness is statistically not significant.
- In line with this, those interviewees with usually not activated ventilation systems in the bedroom at night-time report higher annoyance and sleep disturbances due to aircraft noise and a less pleasant indoor climate in the bedroom than the group of participants with activated ventilation systems. No corresponding statistically significant relationship between the use of the ventilation system and sleep-restfulness could be found.
- As expected from the results above, aircraft noise-related annoyance and sleep disturbances increase with decreasing pleasantness of the indoor climate of the bedroom (correlation coefficients for annoyance vs. indoor climate: $r = -.28$, $p < .000$; for sleep disturbances vs. indoor climate: $r = -.36$, $p < .000$). In addition, sleep-restfulness decreases with decreasing pleasantness of the indoor climate of the bedroom ($r = .25$, $p < .000$).

4 DISCUSSION AND CONCLUSIONS

In autumn 2010 a telephone survey with 765 citizens of Raunheim in the vicinity of Frankfurt Airport was carried out with regard to the use and acceptance of noise insulation measures (sound proof windows, ventilation systems) at home in the bedroom.

As the whole city of Raunheim is included in the night protection zone all residents benefit from the airport's noise protection program, i.e. sound proof windows in part combined with a ventilation system in the bedroom are funded 100% by the airport operator.

The survey results indicate that only in about half of the households entitled to benefit from the insulation program sound proof windows and/or ventilation systems paid by the airport have been claimed. Bedroom windows are predominantly not closed, independent of the participation in the noise insulation program at night-time. This is in line with previous findings^{8-10,14}.

Almost half of the participants owning a ventilation system in the bedroom do not have the system activated during the night. The main reasons not to use the ventilation system at night-time are related to the perceived noisiness and insufficiency of the ventilation system and the deficient indoor climate when having the windows closed and the ventilation system activated.

Those residents reporting to have the bedroom window predominantly closed mostly mentioned aircraft noise as the main reason. However, it was found that they perceive a less pleasant indoor climate in the bedroom and are more annoyed and sleep disturbed by aircraft noise. Similar, those respondents with non-activated ventilation systems in the bedroom during the night reported higher aircraft-related annoyance, sleep disturbances and a less pleasant indoor climate than the group with activated ventilation systems. It seems, that closing the bedroom window and activating the ventilation system because of aircraft noise is in itself annoying. This is in line with findings of Öhrström et al.¹¹ that, among road traffic noise-related disturbances, not being able to keep the bedroom window open was the strongest reported disturbance closely related to sound levels.

One explanation for the lower aircraft noise annoyance and sleep disturbances in case of predominantly open bedroom windows and not activated ventilation systems could be the perceived control and effective coping behavior. This is e.g. assumed by Babisch et al.¹⁴ with regard to physiological stress responses to noise, which they found to be less when windows are open. Another explanation could be the perception of improved indoor climate in case of open windows. Whether one of these explanations, or probably both are true is a matter of future research.

The notion of a disadvantage of an adequate use of noise insulation facilities at home (windows closed, ventilator on) with regard to the (perceived) poorer indoor climate is supported by results of the second study commissioned by the municipality of Raunheim, concerning the thermal behavior of dwellings¹⁵. In this study the authors used numerical models to assess the room temperature and thermal comfort for different building standards and years of construction typical for the buildings in Raunheim. Models for scenarios with varying use of noise insulation facilities in the bedroom at night-time were calculated. The results demonstrate that the thermal comfort is lower for scenarios with closed window and activated ventilator used for airing in comparison to scenarios with open windows instead of activated ventilators (Figure 3).

The results presented in this paper suggest that noise insulation measures at home, in particular sound proof windows and ventilation systems, lack efficiency in terms of reduction of aversive noise effects (annoyance, disturbances).

This is in line e.g. with Fidel and Silvati⁶, who studied the effect of residential acoustic insulation on aircraft noise annoyance and overall found no statistically significant differences between the prevalence of aircraft noise annoyance in treated (with noise insulation measures) and untreated houses in residential areas in the vicinity of Hartsfield International Airport, Atlanta. The results contradict those of the Norwegian Façade Insulation Study⁵, where a significant reduction of road traffic noise annoyance due to the implementation of a façade insulation program was found.

Methodological differences (cross-sectional study⁶ comparing differently treated groups vs. longitudinal study⁵, studying annoyance changes before and after an insulation program implementation) may be one reason for the different study results. Other reasons may refer to the exposure to noise coming from different sources and related to this the importance of quiet bedroom façades. This was found to be relevant for the annoyance reduction due to road traffic noise as studied in the Norwegian study⁵, whereas it seems to be less relevant in case of aircraft noise coming from above, which was the noise source studied by Fidell and Salvati⁶ as well as in the present study.

All in all, for residents living in the vicinity of an airport it is acknowledged that noise insulation programs at the home of residents may have a great potential in reducing indoor sound levels. However, as these measures seem to be less efficient in reducing aversive noise effects they should be treated as a last resort to reduce aircraft noise. Insulation programs at the home of residents cannot replace other noise control measures such as runway alternation, noise optimized flight procedures, temporal (nocturnal) flight limitations, or noise reduction from the source (single plane).

For the future it is suggested to take the study of changes in noise effects more often into account in order to assess the efficacy of noise control measures. With this in mind, the reduction of sound levels by means of noise abatement measures is not necessarily an end in itself but a means to an end, i.e. to reduce aversive effects of noise on human-beings.

5 ACKNOWLEDGEMENTS

The author gratefully acknowledges the funding of the presented research by the municipality of Raunheim. He also thanks Thomas Hasselbeck and Johannes Wolf from GPM (Geoinformatics, Environmental Planning, New Media), Kronberg im Taunus, Germany, and Frank Otto, Zentrum für Umweltbewusstes Bauen e.V., Kassel, Germany, for the pleasant and successful cooperation.

6 REFERENCES

1. Hales Swift, *A Review of the literature related to potential health effects of aircraft noise*, PARTNER Projekt 19 final report, Purdue University, (2010), <http://web.mit.edu/aeroastro/partner/reports/proj19/proj19-healtheffectnoise.pdf>, 03/05/2012.
2. World Health Organization, *Burden of disease from environmental noise. Quantification of healthy life years lost in Europe*, Copenhagen, Denmark: WHO Regional Office for Europe, (2011).
3. E. Greiser, C. Greiser, K. Janhsen, "Night-time aircraft noise increases prevalence of prescriptions of antihypertensive and cardiovascular drugs irrespective social class – the Cologne-Bonn Airport study", *J Public Health*, **15**, 327-337, (2007).
4. L. Järup, W. Babisch, D. Houthuijs, G. Pershagen, K. Katsouyanni, E. Cadum, M.L. Dudley, P. Savigny, I. Seiffert, W. Swart, O. Breugelmans, O. Bluhm, J. Selander, A. Haralabidis, K. Dimakopoulou, P. Soutzi, M. Velonakis, F. Vigna-Tagliani, on behalf of the HYENA study team, "Hypertension and Exposure to noise near airports: the HYENA study", *Environ. Health Persp.*, **116**, 329-333, (2008).

5. A.H. Amundsen, R. Klaeboe, "The Norwegian Façade Insulation Study: The efficacy of façade insulation in reducing noise annoyance due to road traffic", *J Acoust Soc Am*, **129**(3), 1381-1389, (2011).
6. S. Fidell, L. Silvati, "An assessment of the effect of residential acoustic insulation on prevalence of annoyance in an airport community", *J. Acoust Soc Am*, **89**(1), 244-247, (1991).
7. W.A. Utley, I.B. Buller, E.C., Keighley, E. C., J. W. Sargent, "The effectiveness and acceptability of measures for insulating dwellings against traffic noise", *J. Sound Vib.*, **109**, 1-18, (1985).
8. G.M. Aasvang, T. Moum, B. Engdahl, "Self-reported sleep disturbances due to railway noise: exposure-response relationships for nighttime equivalent and maximum noise levels", *J Acoust Soc Am*, **124**(1), 257-68, (2008).
9. W. Passchier-Vermeer, H. Vos, J.H.M. Steenbekkers, F.D. van der Ploeg, K. Groothuis-Oudshoorn, *Sleep disturbance and aircraft noise exposure. Report No. 2002.027*, TNO-PG, Leiden, The Netherlands, (2002).
10. D. Schreckenber, M. Meis, *Effects of aircraft noise on noise annoyance and quality of life around Frankfurt Airport*, Final abridged report. ZEUS GmbH, Hagen, (2006), URL: <http://www.verkehrslaermwirkung.de/FRA070222.pdf>, last access on 12/05/2012.
11. E. Öhrström, A. Skanberg, H. Svensson, A. Gidlöf-Gunnarsson, "Effects of road traffic noise and the benefit of access to quietness", *J. Sound Vib*, **295**, 40-59, (2006).
12. R. van Poll, *The perceived quality of the urban residential environment*, Westrom Drukkerij, Roermond, The Netherlands, (1997).
13. International Organization for Standardization, "*Acoustics – Assessment of noise annoyance by means of social and socio-acoustic surveys*", ISO/TS 15666, Geneva, (2003).
14. W. Babisch, H. Fromme, A. Beyer, A., H. Ising, "Increased catecholamine levels in urine in subjects exposed to road traffic noise: The role of stress hormones in noise research", *Environ Intern*, **26**(7-8), 475-481, (2001).
15. F. Otto, L. Mueller, *Untersuchung des sommerlichen Wärmeverhaltens von Wohnräumen in Raunheim (Study of thermal behavior of dwellings in Raunheim)*, Final report, Zentrum für Umweltbewusstes Bauen e.V., Kassel, Germany, (2011a).
16. F. Otto, L. Mueller, *Untersuchung des sommerlichen Wärmeverhaltens von Wohnräumen in Raunheim (Study of thermal behavior of dwellings in Raunheim)*, presented by J. Wolf, T. Hasselbeck, GPM, on the 2nd Conference against Changes of German Air Traffic Act, Kelsterbach, Germany, 28/09/11, (2011b).

Table 1 – Predominant window position in the bedroom in warmer seasons and funding of the insulation in the bedroom

Predominant window position in bedroom in warmer seasons	Noise insulation in bedroom financed by ...								Total	
	household / owner		airport operator		others		don't know		N	%
	N	%	N	%	N	%	N	%		
closed	68	33	161	39	8	38	42	33	279	37
partially open	74	36	116	28	5	24	52	41	247	32
open	65	31	127	31	8	38	26	20	226	30
no respond	0	0	5	1	0	0	8	6	13	2
Total	207	100	409	100	21	100	128	100	765	100

Table 2 – Use of bedroom ventilation system at night-time in total and grouped by funding of the insulation in the bedroom

Use of ventilation system in bedroom at night-time	Noise insulation in bedroom funded by the airport operator				Total respondents possessing a ventilation system in their bedroom	
	yes		no / don't know		N	%
	N	%	N	%		
no	130	42%	103	58%	233	48%
yes	177	57%	71	40%	248	51%
don't know	2	1%	3	2%	5	1%
Total	309	100%	177	100%	486	100%

Table 3 – Relationship between annoyance and sleep disturbances due to aircraft noise, sleep-restfulness, indoor climate and window position and use of ventilation system in the bedroom.

	Aircraft noise annoyance		Sleep disturbances due to aircraft noise		Sleep-restfulness		Indoor climate	
	M	SD	M	SD	M	SD	M	SD
<i>Window position (n = 742-750)</i>								
closed	3.8	1.1	2.9	1.2	3.1	1.2	3.0	1.1
half-open/tilted	3.3	1.3	2.4	1.2	3.3	1.1	3.4	1.1
open	3.5	1.3	2.6	1.2	3.2	1.2	3.6	1.0
Significance	***		***		n.s.		***	
<i>Use of ventilation system (n = 474- 481)</i>								
no	3.5	1.3	2.5	1.2	3.2	1.2	3.5	1.1
yes	3.7	1.1	2.8	1.2	3.1	1.1	3.1	1.1
Significance	*		*		n.s.		**	
<i>Indoor climate ... pleasant (n = 706-714)</i>								
1: not	4.2	0.8	3.7	1.0	2.5	1.0		
2: a little	4.2	0.9	3.3	1.2	2.6	1.2		
3: moderately	3.6	1.1	2.7	1.2	3.3	1.1		
4: rather	3.3	1.3	2.3	1.1	3.2	1.2		
5: very	3.1	1.5	2.1	1.2	3.7	1.1		
Significance	***		***		***			

M = mean; SD = standard deviation; * p < .05; *** p < .001

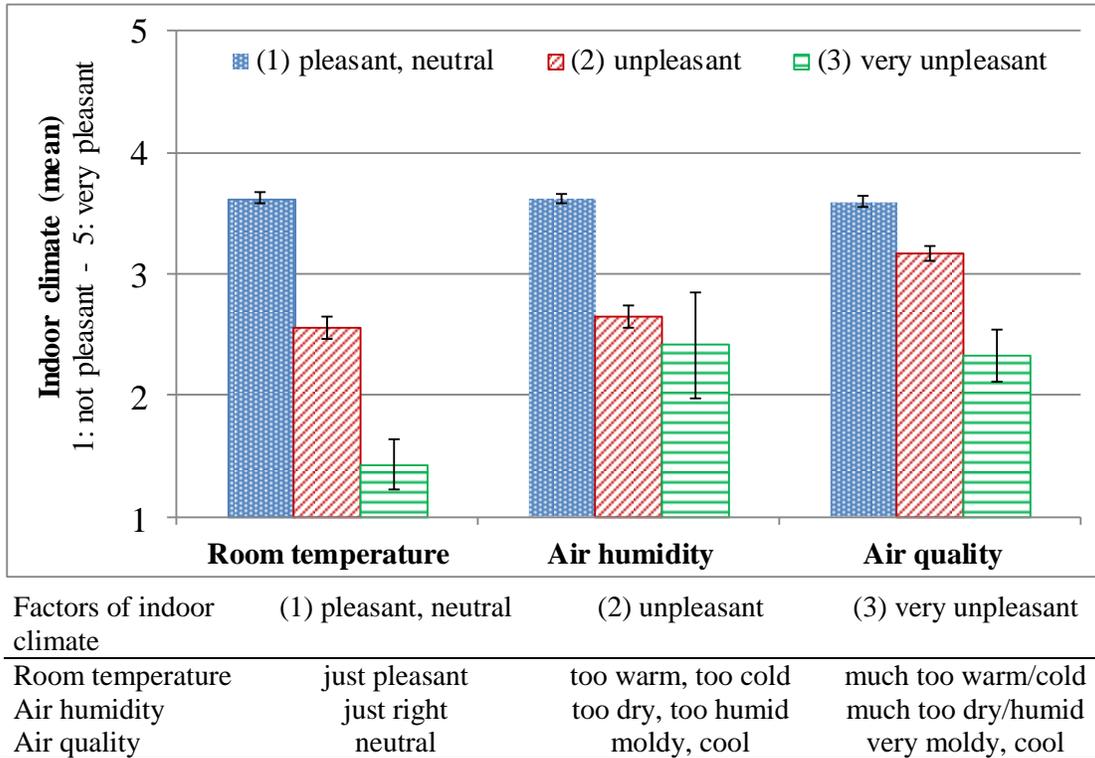


Fig. 1 - Perceived indoor climate in the bedroom grouped by the perceived pleasantness of temperature, air humidity, and air quality.

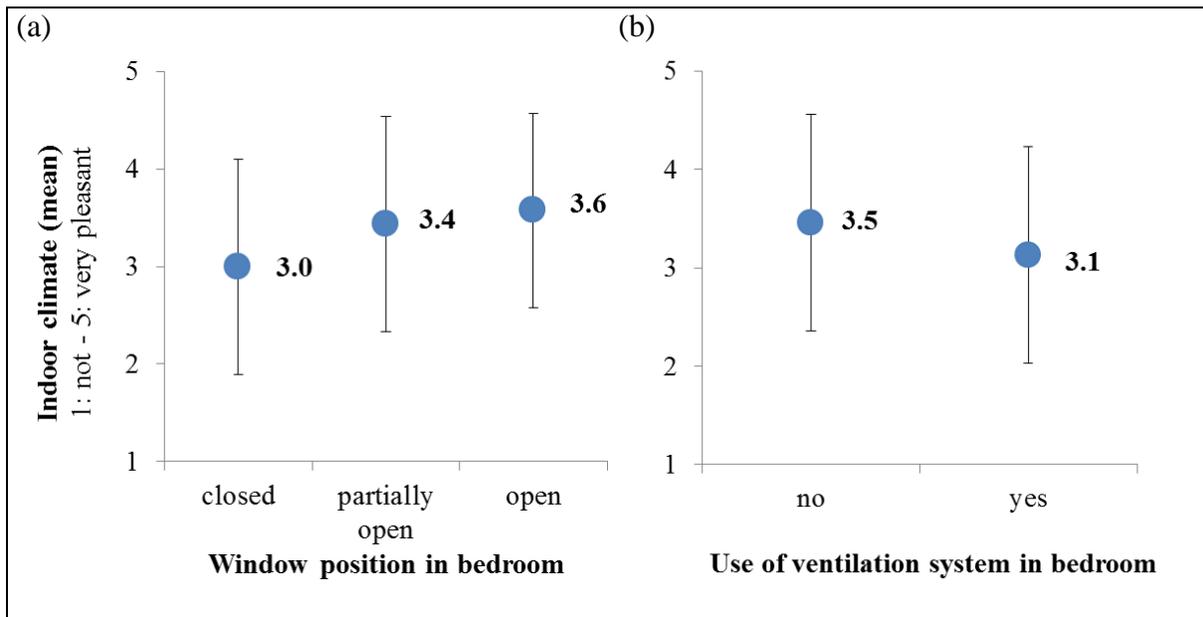


Fig. 2 - Relationship between perceived indoor climate and the window position (a) and the use of the ventilation system (b) in the bedroom.

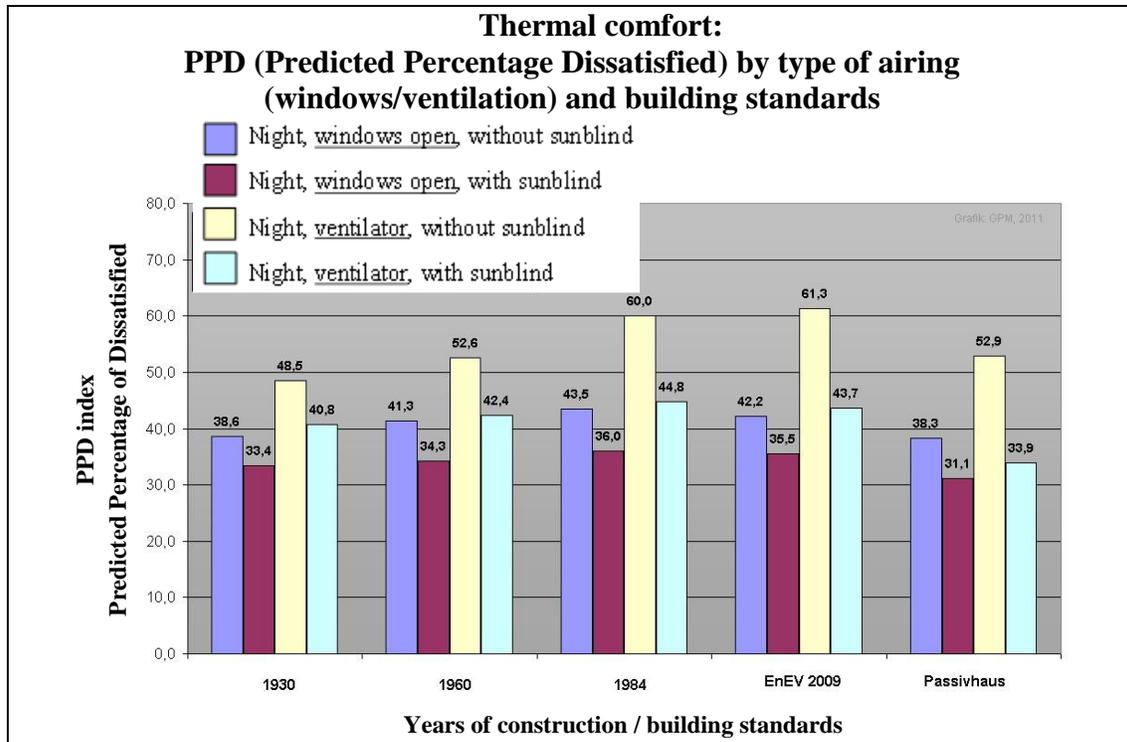


Fig. 3 - Effects of noise insulation measures on thermal comfort: PPD (Predicted Percentage Dissatisfied) by type of airing and building standards. Source of data: ¹⁵, source of figure: ¹⁶