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User perspectives on outdoor noise in buildings with operable windows

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Abstract
Recent research suggests that buildings with operable windows in general, and mixed-mode (MM) buildings in particular can provide improved thermal comfort and control opportunities for users. Yet, there have been concerns about outdoor noise sources like traffic or construction noise when windows are opened. Concerns like these may hinder the installation of operable windows in buildings. This paper examines 23,000 office building occupants' perspectives on noise from both sealed and naturally ventilated/MM buildings. Results suggest that occupants near operable windows are more satisfied than those near sealed windows or those far from either window type. Among occupants dissatisfied with noise, complaints about indoor noise sources --like people talking-- are about 10 times more prevalent than outdoor noise complaints.

Keywords: acoustics, occupant satisfaction, office design

Background

Office workers generally prefer access to a window. Studies suggest that the sunlight windows provide is relaxing; (Boubekri, et al., 1991) and the presence of a window is thought to increase motivation (Stone, 1988). Windows that are operable provide additional benefits to occupants such as an improved ability to manage their comfort. In fact, occupants can be comfortable over a wide range of temperatures in some buildings with operable windows (Brager et al., 2004). Since occupants can be comfortable during more conditions in such a building, HVAC system demand is reduced, which also saves energy. Unfortunately, most office buildings include sealed --rather than operable-- windows in the name of tightly controlled indoor environments. Therefore, most occupants miss these additional benefits and building owners miss potential energy savings.

While there are many positives to operable windows, there are potential negatives too. Dust, pollen and other pollutants may enter the building via outside air. Operable windows may present safety concerns by offering additional entry points into the building. Additionally, occupants in buildings with operable windows will likely be exposed to more outdoor noise than occupants in a sealed buildings will. These aspects may hinder the inclusion of operable windows in new buildings and retrofit installations in existing buildings.

This paper analyses occupant perceptions of outdoor noise in an attempt to addresses concerns about outdoor noise intrusion.[1] More specifically, it presents analysis of six variables related to outdoor noise. It compares noise responses in operable and sealed buildings between differing land use densities (e.g. suburban or downtown); from occupants near and far from windows; by how far above ground-level noise the occupant sat; whether the building had double-paned glass in its windows; and over several window to wall ratio groupings. The study's sample is 92 office buildings in four countries, representing approximately 23,000 occupants.

Literature

The effect of noise on office occupants is certainly worth considering. Poor acoustic environments can interfere with communication, create annoyance, stress and impede work performance. The World Health Organization (WHO) recommends a background noise level lower than 45 db(A) for good speech intelligibility --the ability to understand others (WHO, 1980). The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) also suggests a noise level less than 45db(A) for open plan offices (ASHRAE, 2011.) Noise from outdoor sources would add 15dB(A) to any existing interior noise (CSA, 1998) so that interior noise levels in operable buildings would need to be lower than in sealed buildings to meet these levels. It is not known how many office buildings in operation meet these standards. Better monitoring and reporting is needed (National Institute of Building Sciences, 2012). The literature makes clear however, that acoustics in general, falls short of office workers' expectations.

Workers in open office environments report the worst acoustic problems (Jensen et al., 2005; Tuomaala et al., 2009) and this pattern persists even in 'green' rated buildings (Abbaszadeh et al., 2006). Occupant comments express frustration and distress about poor acoustic environments, (Moezzi and Goins, 2011) which may affect morale. Finally, absenteeism may also increase if acoustic conditions are bad enough (Fried et al., 2002).

The relationship between noise and the performance of office workers is especially well researched. One study showed that noise under 85dB --the level of a commercial truck-- slowed work performance, but did not affect accuracy (Guilian et al., 1986). Noise of this sort would also hinder telephone and other conversations. (Miller, 1981). More recent work has expanded on these findings by showing that reading tasks are most affected by noise (Furnham, 2002), a common task among office workers. The frequency of noise matters as well, with unpredictable noise also being problematic for occupants (Theologus, 1974). Construction noise and sirens might fall into this category.

Noise is clearly a problem for occupants. This paper's concerned is the degree outdoor noise is perceived to be a contributor to noise problems in offices. More specifically, noise from traffic, construction and other outdoor activities and equipment. It is well established that traffic noise is a particular source of noise annoyance (Griffiths et al., 1967; Matsumura, 1991; Miedema et al.,

[1] This is a different activity than determining the sound levels at which outdoor noise becomes an issue for occupants. Instead, we present standards in the upcoming literature review that relate to the prevention of outdoor noise dissatisfaction. Additionally, our results suggest that the building practices represented in CBE's database do a reasonable job of dealing with outdoor noise. Design barriers are not the issue here. Instead, the social and organizational barriers related to outdoor noise persist and are what we address in this paper.

1999; Ouis, 2001). Short exposures to traffic noise have not been shown to affect work performance (Ljunberg, 2007). Still, long exposures like those experienced in an office building might. Additionally, outdoor noise is certainly an irritator and may affect work satisfaction, intent to stay and morale.

Data and Methods

The Center for the Built Environment (CBE) has developed a web-based survey about indoor environmental quality (IEQ). The survey asks about seven IEQ areas including noise and acoustics (Zagreus et al, 2004). When respondents indicate dissatisfaction with noise, they are asked follow-up questions about the sources of their dissatisfaction (Figure 2). The list of sources includes both interior and exterior noise concerns. Respondents can write in additional sources of dissatisfaction if needed. Occupants are also offered the opportunity to write free-text comments about noise.

The survey has been continually administered in buildings since 2000. The complete dataset now includes responses from over 575 buildings and over 65,000 people. The set of buildings is a convenience sample. Still, the database is statistically very powerful due to its size. The survey instrument is largely the same in each building, so responses can be compared across buildings.

Figure 1 -- Noise satisfaction question used in the CBE survey.

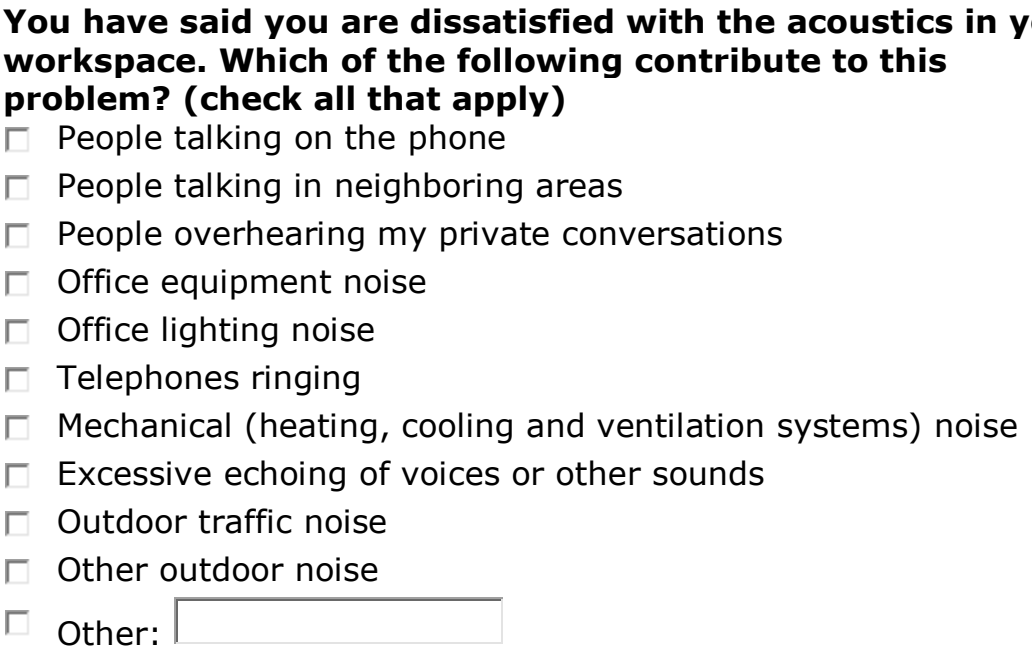

Figure 2 -- Sources of acoustics dissatisfaction question used in CBE survey.

For each building, CBE also captures over 100 building characteristics, including indicators of land use density, window to wall ratio, number of storeys, whether the windows have double-pane glass and whether the windows open. The data used in this paper represent the buildings for which all of the aforementioned factors are completed. This resulted in a sample of 92 buildings and approximately 23,000 occupants.

		near window	interior
% of people	sealed	36%	60%
	operable	11%	81%

% of buildings	sealed	80%
	operable	20%

	location	**%**
% of buildings	downtown	62%
	urban	21%
	suburban	14%
	rural	3%

Figure 3 -- Summary statistics for the analyzed sample.

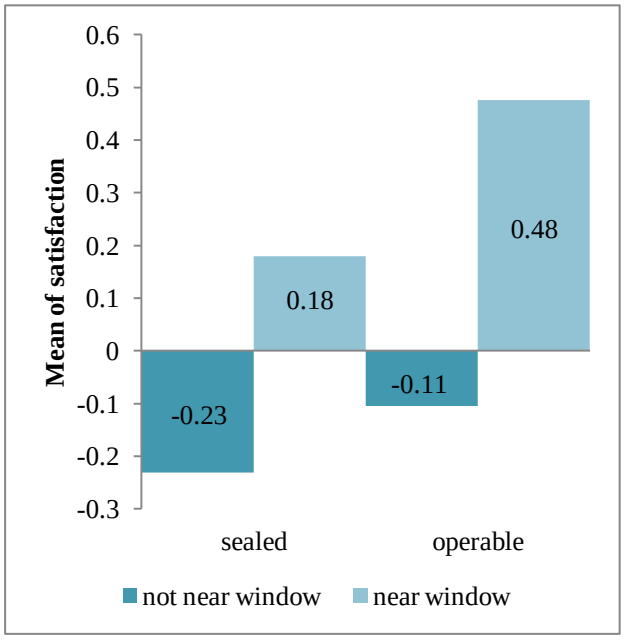

Figure 4 -- Noise satisfaction averages. n = 19,530.

Numeric data for each respondent were analyzed, as were the 2,100 free text comments about noise. Numeric data were analyzed in Excel. All numeric results are statistically significant to a 99% confidence level unless otherwise noted. Text data were analyzed in SPSS Text Analytics for Surveys. Over 80% of the comments were categorized and included in our results.[2]

About 2/3 of the sample buildings are in the US. The remaining buildings are in Finland, Canada and Australia. A majority of the buildings are situated in central business districts --downtowns-- densely populated areas likely to have high levels of outdoor noise. Eighty percent of the buildings were sealed, while 20% offered operable windows. For both sealed and operable buildings, a majority of occupants site more than 15 feet from their nearest windows (Fig. 3).

Results

The data show that occupants in buildings with operable windows are more satisfied than their counterparts in sealed buildings are (Fig. 4). More specifically, occupants near windows in operable buildings are more satisfied than their counterparts near windows in sealed buildings. This pattern continues to be true even in potentially noisier areas like downtowns and other urban areas (Fig. 5). When asked about specific sources of dissatisfaction, interior noise sources were much more of a problem than outdoor ones like traffic noise. This may explain why noise

[2] There were no physical measurements of noise available for any of these sites.

satisfaction does not respond much to operable windows, as indoor noise is a much greater concern for occupants.

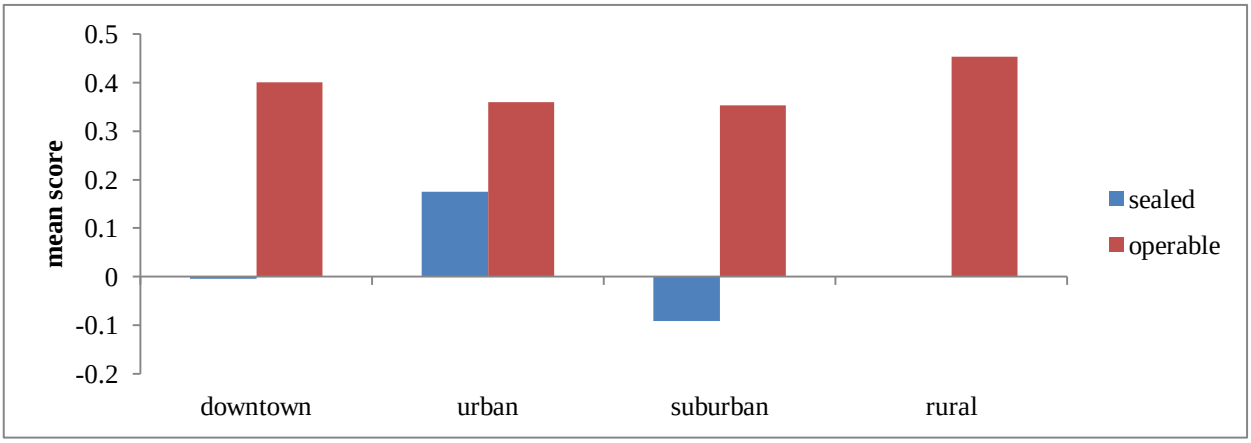

Figure 5 -- Noise satisfaction averages by land use density, n = 19,530.

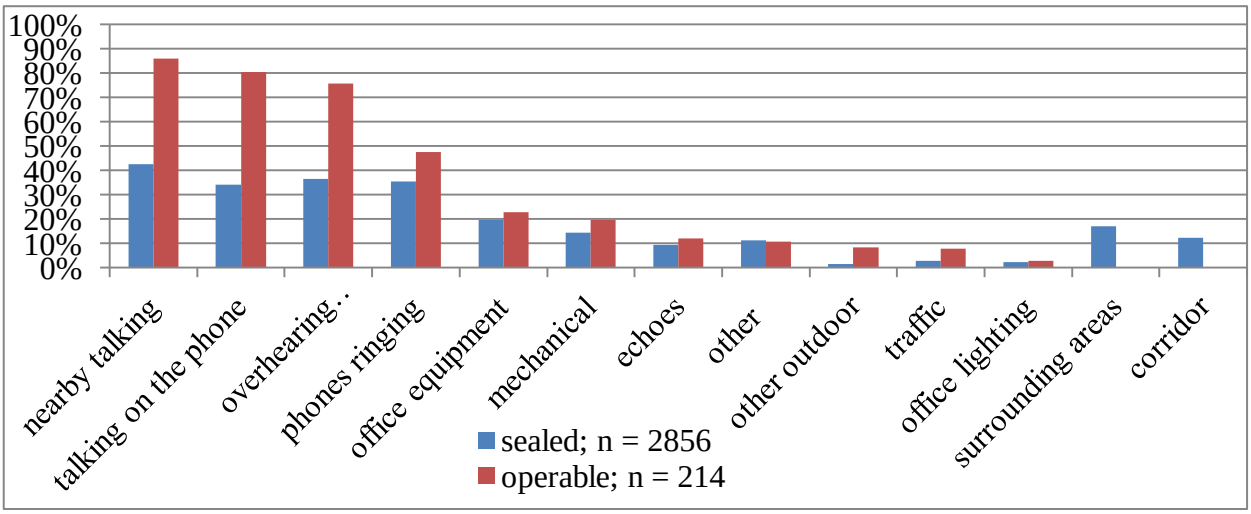

Figure 6 -- Interior sources of noise dissatisfaction.

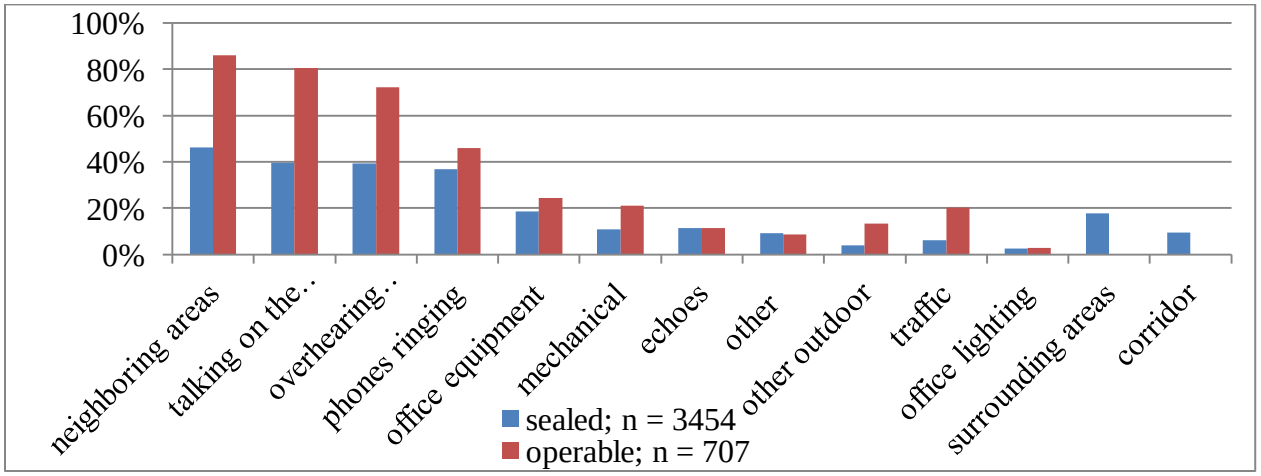

Figure 7 -- Near window sources of noise dissatisfaction.

People talking was the greatest concern (Fig 6 – 7). While 80% of those dissatisfied and near windows in operable window buildings cited people talking as a problem, only 20% cited traffic noise as a problem. People talking is cited nine to eleven times more frequently that outdoor noise sources.

	Correlations	
ringing phones	-0.37	***
Talking nearby	-0.36	***
people talking on phones	-0.32	***
people in surrounding offices	-0.28	
office equipment noise	-0.27	**
talking in corridors	-0.23	***
people overhearing my conversations	-0.23	***
echoes	-0.19	
mechanical system noise	-0.19	*
other sources	-0.19	*
traffic noise	-0.13	***
other outdoor noise	-0.11	***
lighting noise	-0.09	***

Figure 8 -- Correlation of noise sources and satisfaction. (*, p<.01; **, p<.05; *p<.1).**

People that complain about phones ringing are likely to be among the occupants most dissatisfied with noise (Fig. 8). People talking follows this. Traffic noise and other outdoor noise sources are towards the bottom of the list, suggesting that these are not extreme annoyances when they are a problem. The respondents are like to be only slightly dissatisfied whereas the aforementioned would be very dissatisfied.

Among outdoor noise sources of concern, the free text comments highlight that construction noise can be a significant problem when present. It is the second most mentioned outdoor noise source with 37 occurrences among over 1,000 free-text comments about noise sources (Fig 9). It is however, very temporal and generally recedes with time. By far most text comments relate to physical features of the office or the design of individual workspaces.

responses	source
203	coworkers talking to each other
107	noise from phones or phone conversations
85	noise from coworkers walking
66	ineffective partitions/cubicles
59	music or radios
37	construction noise
32	noise from conference rooms
31	sound through walls
27	white noise is distracting
27	noise from cleaning crews
27	other outside noise (e.g. trains, motorcades, sirens, people outside)

Figure 9 - Free text comments about noise. 86% of comments categorized.

While there is only small dissatisfaction with outdoor noise, it is still worth considering what design elements might help attenuate dissatisfaction. There may be locations where outdoor noise is of special concern. For this reason, we consider traffic noise (the more problematic of the two outdoor sources) and the effect of insulated (double-pane) glass, window to wall ratio, and the floor on which the occupant sits, for occupants near windows for all buildings. We consider both operable and sealed buildings together here since it is likely that an occupant would close an operable window when outdoor noise is a problem. Thus, the sealed and operable building would have the same condition in this circumstance.

There is a small increase among those near windows that cite traffic (and other outdoor noise sources) as problems in buildings without insulated glass (not shown). This suggests that double-pane glass (or greater) may help attenuate dissatisfaction with outdoor noise to a small degree.

There are also small differences in traffic noise dissatisfaction between floors (Fig. 10). The data show a constant decrease in traffic noise as a source of dissatisfaction as the floor number

Floor	1	2	3	4	5	6	7	8	9	10
% satisfied	32%	32%	28%	29%	27%	27%	25%	25%	23%	25%

Figure 10 -- Percentage of occupants citing traffic noise dissatisfaction by floor.

increases. This pattern holds for floors 1 through 9. Traffic noise dissatisfaction increases at floor 10 however.

Buildings with a facade composed of 1/4 to 1/2 windows show the most traffic dissatisfaction. Strangely, buildings with more windows have less traffic noise issues reported (Fig. 11). This suggests that there is no relationship between window to wall ratio; some other building characteristic (a confounding variable) might be at play here.

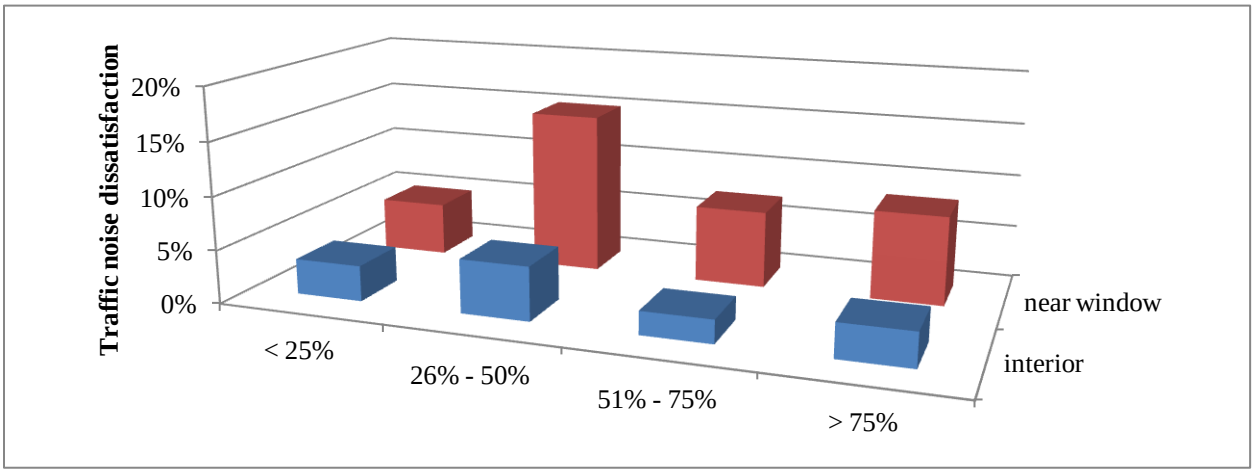

Figure 4 -- Percentage of occupants citing traffic noise dissatisfaction by window to wall ratio.

Conclusion

While noise more generally is a problem for occupants in many buildings, these data suggest outdoor is not a significant problem for office occupants as survey respondents near windows are more satisfied with noise than people without windows. Occupants near operable windows are the most satisfied overall. Among occupants dissatisfied with noise, indoor noise sources --like people talking-- are about ten times more prevalent in offices. Among problematic noise sources, a phone ringing is most likely to create the strongest negative response.

Construction noise is of concern to occupants when present. The number of reports of problems with construction noise is small, but the comments are very passionate. For this reason, this noise source deserves special attention.

When outdoor noise is a problem, several options exist to attenuate dissatisfaction. Traffic noise complaints recede in the presence of double-pane windows and when occupants are on higher floors. This suggests that one way to respond to outdoor noise complaints is to move noise sensitive occupants to a higher floor or put them near windows with two or more panes of glass.

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References

1. Abbaszadeh, S., L. Zagreus, D. Lehrer, and C. Huizenga. 2006. Occupant satisfaction with indoor environmental quality in green buildings. In Proceedings of Healthy Buildings, 3:365–370.
2. ASHRAE handbook. Heating, ventilating and air conditioning. [HVAC Systems and equipment. HVAC Applications]. Atlanta: ASHRAE, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 19uu.
3. Banbury, S, and D Berry. 1998. "Disruption of office related tasks by speech and office noise." British Journal of Psychology 89: 494-517.
4. Boubekri, Mohamed, Robert B. Hull, and Lester L. Boyer. 1991. "Impact of Window Size and Sunlight Penetration on Office Workers' Mood and Satisfaction." Environment and Behavior 23 (4) (July 1): 474 -493. doi:10.1177/0013916591234004.
5. Brager, G., G. Paliaga, and R. De Dear. 2004. "Operable windows, personal control and occupant comfort."
6. Charles M. Salter Associates. 1998. Acoustics : architecture, engineering, the environment. San Francisco [Calif.]: William Stout Publishers.
7. D., Ouis. 2001. "Annoyance from road traffic noise: A review." Journal of Environmental Psychology 21 (1) (March): 101-120. doi:10.1006/jevp.2000.0187.
8. Fried, Yitzhak, Samuel Melamed, and Haim A Ben-David. 2002. "The joint effects of noise, job complexity, and gender on employee sickness absence: An exploratory study across 21 organizations — the CORDIS study." Journal of Occupational and Organizational Psychology 75 (2) (June 1): 131-144. doi:10.1348/09631790260098181.
9. Furnham A., and Strbac L. 2002. "Music is as distracting as noise: the differential distraction of background music and noise on the cognitive test performance of introverts and extraverts." Ergonomics 45 (3): 203-217.
10. Griffiths, I.D., and F.J. Langdon. 1968. "Subjective response to road traffic noise." Journal of Sound and Vibration 8 (1) (July): 16-32. doi:10.1016/0022-460X(68)90191-0.
11. Gulian, E., and J. R. Thomas. 1986. "The effects of noise, cognitive set and gender on mental arithmetic performance." British Journal of Psychology 77 (4) (November): 503-511. doi:10.1111/j.2044-8295.1986.tb02214.x.
12. Jensen, K., and Edward Arens. 2005. Acoustical quality in office workstations, as assessed by occupant surveys. September 4. http://www.escholarship.org/uc/item/0zm2z3jg.
13. Ljungberg, Jessica K., and Gregory Neely. 2007. "Stress, subjective experience and cognitive performance during exposure to noise and vibration." Journal of Environmental Psychology 27 (1) (March): 44-54. doi:10.1016/j.jenvp.2006.12.003.

14. Matsumura, Y., and R. Rylander. 1991. “Noise sensitivity and road traffic annoyance in a population sample.” Journal of Sound and Vibration 151 (3) (December 22): 415-419. doi:10.1016/0022-460X(91)90538-U.
15. Miedema, Henk M. E., and Henk Vos. 1999. “Demographic and attitudinal factors that modify annoyance from transportation noise.” The Journal of the Acoustical Society of America 105 (6): 3336. doi:10.1121/1.424662.
16. Miller, Laymon N, and Beranek Bolt. 1981. Noise control for buildings and manufacturing plants. Cambridge, Mass.: Bolt, Beranek and Newman, Inc.
17. Moezzi, Mithra, and John Goins. 2011. “Text mining for occupant perspectives on the physical workplace.” Building Research & Information 39 (2): 169.
18. National Institute of Building Sciences. 2012. "Data Need for Achieving High-Performance Buildings." http://www.nibs.org/client/assets/files/nibs/NIBS_DataCollectionReport.pdf.
19. Stone, Nancy J. 1998. “Windows and Environmental Cues on Performance and Mood.” Environment and Behavior 30 (3) (May 1): 306 -321. doi:10.1177/001391659803000303.
20. Theologus, George C., George R. Wheaton, and Edwin A. Fleishman. 1974. “Effects of intermittent, moderate intensity noise stress on human performance.” Journal of Applied Psychology;Journal of Applied Psychology 59 (5): 539-547. doi:10.1037/h0037336.
21. World Health Organization. 1980. Environmental Health Criteria for Noise. http://www.inchem.org/documents/ehc/ehc/ehc012.htm#SubSectionNumber:1.1.3.
22. Zagreus, Leah, Charlie Huizenga, and Edward Arens. 2004. A web-based POE tool for measuring indoor environmental quality. April 29. http://www.escholarship.org/uc/item/56s462z4.