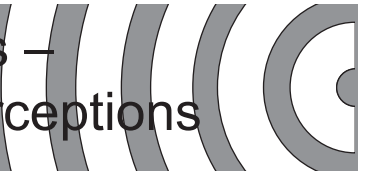


Acoustic Conditions In Sustainable Buildings – Results of a Worldwide Survey of Users’ Perceptions



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A paper previously presented at ISSA 2010, 29-31 August 2010, Auckland

Abstract

With the trend to sustainability and energy efficiency, buildings are being constructed that are attempting to be as ‘green’ as possible. One objective in this form of design is to provide a higher level of interior environmental quality than buildings that use conventional practices. Post Occupancy Evaluations have been carried out on 36 sustainable buildings in 11 different countries. This paper describes and analyses the users’ overall perceptions of the acoustical conditions and the noise sources (in particular noise from colleagues, from other people, and from both inside and outside sources) in these buildings. The results from these analyses showed that people rate the overall interior environment of these sustainable buildings highly. However, the acoustic aspect tended to score rather less well than some other aspects of the interior environment. A strong correlation was found between the occupants’ overall perception of noise and their perception of productivity in the workplace.

Introduction

Over the last decade or so building designers and developers have been producing sustainable buildings for their more environmentally conscious clients. Many of these buildings have been rated highly in terms of relevant Building Sustainability Rating Tools (BSRTs) or have received awards for their low energy design. These ratings and awards are based on the building design and its potential for low energy and sustainable operation, and their focus tends to be on technical aspects of new building designs [1]. Indoor environmental quality is certainly one of these aspects, but the concern is usually with the provision of comfortable temperatures and humidities, adequate air quality, sufficient lighting and appropriate acoustic conditions (all of which are specifiable and measurable).

Our interest has been in how these buildings are performing from the point of view of the building users. While measurements of all the physical factors (inside and outside noise levels, sound transmission and impact characteristics, reverberation times, and so on) would provide insights into the acoustical performance of these buildings, at the end of the day what really matters is whether sustainable buildings are perceived to be acoustically comfortable by their occupants. Buildings that

perform poorly from the users’ point of view are unlikely to be sustainable in the long term.

It is only very recently that there have been some moves towards developing BSRTs that assess the environmental quality of the building once it is in operation. The groundbreaking Indoor Environmental Quality protocol of the Australian NABERS suite [2] of BSRTs for example, is designed to enable such an assessment. Not only does it specify a range of physical measurements, it also involves conducting a questionnaire survey of the building occupants [3]. Two methods are approved for the survey, one developed by Building Use Studies of York, UK, the other by the Center for the Built Environment, University of California, Berkeley, USA. Our aim here, using the Building Use Studies survey methodology under licence [4], was to determine whether the occupants of a worldwide set of 36 sustainable buildings found them to be acoustically comfortable.

Methodology

For the last five years the performance in practice of a large number of commercial and institutional buildings in 11 countries worldwide has been investigated by Baird [5], to ascertain the users’ perception of a range of factors: operational, environmental (including thermal, acoustic and lighting aspects),

personal control, and satisfaction.

We are firmly of the belief that people can provide one of the best measures of building performance since “for many aspects of a building the true experts are the people who know most about using it – the users” (refer to Baird et al [6] for more explanation). People know if they are too hot or too cold, have too much or insufficient light, whether it is too noisy, how comfortable they are overall, and in the final analysis, how conditions in the building are affecting their health and productivity.

While many individual quantitative measurements of temperature, lighting, acoustics, etc. are feasible, none of them can readily integrate an individual’s sense of comfort overall. In the case of productivity, Leaman and Bordass [7] have noted that

It is impossible to measure productivity ‘objectively’ across a building in use; results have to be based on subjective responses of samples of occupants drawn from cross-sections of users. This is not to say that subjectively obtained data are in any way inferior. It just means, as Gary Raw [a lead researcher in the field of Sick Building Syndrome] so aptly said “in buildings, people are the best measuring instruments: they are just harder to calibrate”.

Thus the questionnaire simply asks respondents to assess whether they perceive themselves to be more or less comfortable or productive in the

building they occupy.

This paper is part of a series [8] [9] [10] describing different aspects of the findings of the authors' research programme. It focuses on the environmental factors relating to the occupants' perception of noise, including that from colleagues and other people, and from sources both inside and outside the building, as appropriate to the building layout and location.

The Buildings

The buildings surveyed were as follows, by country:

- Australia: 40 Albert Street* and 60L*, Melbourne; Red Centre and Institute of Languages*, UNSW, Sydney; Student Centre and General Purposes Building, Newcastle University; Scottsdale Forest Ecocentre, Tasmania.
- Canada: Computer Science and Engineering, York University; Liu Institute, University of British Columbia; Toronto Military Families Resources Centre; National Engineering Yards*, Vancouver.
- Germany: Science Park*, Gelsenkirchen.
- India: Torrent Research Centre, PDEC Buildings and AC Buildings, Ahmedabad.
- Ireland: St Mary's Credit Union*, Navan.
- Japan: Nikken Sekkei HQ*, Tokyo; Tokyo Gas Earthport*, Yokohama.
- Malaysia: MEWC HQ*, Putrajaya.
- New Zealand: AUT Akoranga, Auckland; Landcare Research, Auckland; Erskine Building, University of Canterbury, University of Otago Library*, Dunedin; Nelson Library*; Universal College of Learning*, Palmerston North; Environment House*, Wellington; Conservation House*, Wellington; Paraparaumu Public Library*.
- Singapore: Institute of Technical Education*, Bishan.
- UK: Arup Campus, Solihull; City Hall*, London; Eden Foundation, St Austell; Gifford Studios, Southampton; Renewable Energy Systems HQ, Kings Langley; ZICER Building, University of East Anglia.
- USA: Natural Resources Defence

Council*, California; NRG Systems, Vermont.

These were selected on the basis of their sustainability 'credentials'. Virtually all of them were recipients of national awards for sustainable or low energy design or highly rated in terms of their respective country's building sustainability rating tool (Leed [11], BRAEEM [12], CASBEE [13], Green Star Australia [14] Green Globes [15], etc) or in some way pioneered green architecture. Of course, willingness on the part of the building owner and tenants to be surveyed was also an essential prerequisite, and not all building owners approached felt in a position to accept our invitation.

The 36 buildings were all commercial or institutional in nature. Sixteen of the buildings accommodated office activities predominantly, eleven were tertiary-level academic teaching buildings, four housed laboratories or research organisations, three were libraries, and two contained a combination of light industrial and administrative functions.

2,540 staff responded to the questionnaire, the vast majority scoring every question. Students and library visitors were also surveyed where relevant, using a shorter questionnaire, but these results are not included here as the focus is on the perceptions of the permanent staff. Numbers ranged from a low of 11 responses from the small staff group at the Paraparaumu Public Library to a high of 334 at London City Hall, with a mean of 69 respondents per building. For 97 per cent of the respondents (45.4 per cent female; 54.6 per cent male), the building was their normal place of business – the rest tended to be contractors of one kind or another. They worked 4.74 days per week on average and 7.92 hours per day, of which around 6.34 were spent at their desk or work space and 5.46 at a computer screen. The ratio of under to over 30s was 29.5 to 70.5 per cent and most (75.2 per cent) had worked in the building for more than a year, 61.0 per cent at the same desk or work area. In broad terms, around 30 per cent of respondents either had a single office or shared with more than eight others: while around 13.3 per cent each sharing with either one, two to four, or five to eight colleagues.

Other than those in India, Malaysia and Singapore, all the buildings were in temperate climates of one kind or another (ranging from warm-temperate to cold-temperate). Eighteen (indicated by an asterisk) were located in urban or suburban surroundings, while the remaining eighteen were located in campus settings or in the country. Their systems of ventilation ranged from full air conditioning, through mixed-mode, to natural ventilation.

The Acoustics Questions

The 'Acoustics' questions on the survey form were introduced using the following statement: 'How would you describe noise in your normal work area?'- together with the footnote 'This question refers to conditions all year round'. Respondents were then asked to rate the following five factors on a 7-point scale:

- Noise Overall – is it unsatisfactory or satisfactory?
- Noise from Colleagues – is there too little or too much?
- Noise from Other People – is there too little or too much?
- Other noise from Inside – is there too little or too much?
- Noise from Outside – is there too little or too much?

While a 7-point scale was used throughout, it should be noted that the 'ideal' score differed depending on the question. In the case of Noise Overall the ideal would be '7'; while a '4' would be ideal for all the others.

Results

In this section the results will be presented and analysed, first with an overview of the average scores for each question, followed by a look at the shapes of their distributions over the set of buildings, and then the results of some correlations between Noise Overall and a number of other key performance factors.

The average scores for each of the five questions are presented in Table 1 in terms of their mean and standard deviation (SD) values for the relevant number (N) of buildings. Also listed are the corresponding benchmark (BMK) scores (with the mean and 95% limits based on the average of the previous 50



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buildings assessed by this method at the time of each survey).

As can be seen, the occupants' perception of Noise Overall has a mean score of 4.40 on a scale where '7' would be the ideal. It is also higher than the benchmark score of 4.17 and greater than the upper limit value of 4.31, indicating a significant difference.

All the other factors (for which a '4'

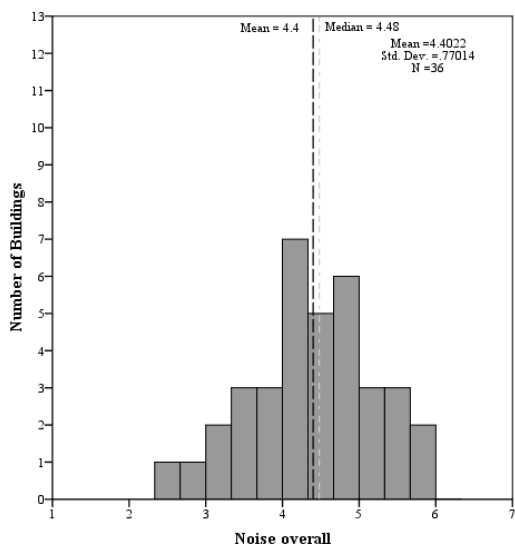
would be the ideal) score very close to their respective benchmarks and are well within the corresponding limits. In the case of noises from *Colleagues*, *Others*, and *Inside*, the mean score is just over 4, indicating a perception of slightly too much noise; while in the case of noise from *Outside*, the mean is just under 4, indicating slightly too little.

The Standard Deviation (SD) of the scores for each factor is also noted in

Table 1 - the distribution of the mean scores over the set of buildings will be examined further in what follows.

Noise Overall

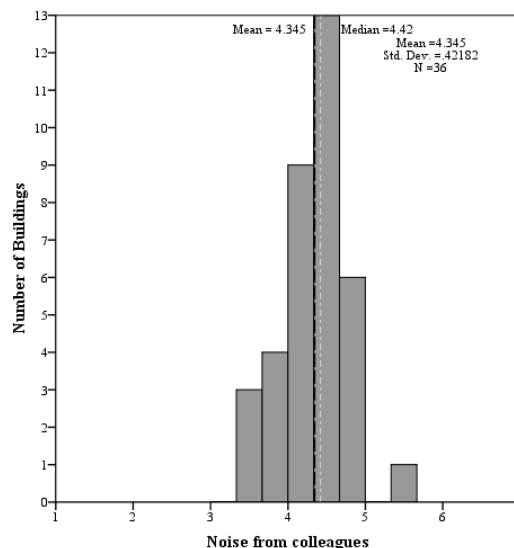
Figure 1 shows the distribution of the mean *Noise Overall* scores for each of the buildings in the sample. In this context these scores represent the occupants' overall perceptions of the acoustical environmental conditions in the



(Satisfactory)

(Unsatisfactory)

Figure 1. Distribution of 'Noise Overall' scores



(Too little)

(Too much)

Figure 2. Distribution of 'noise from Colleagues' scores

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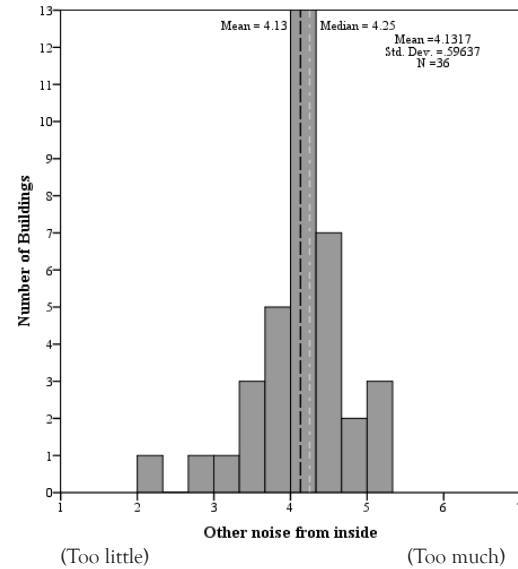
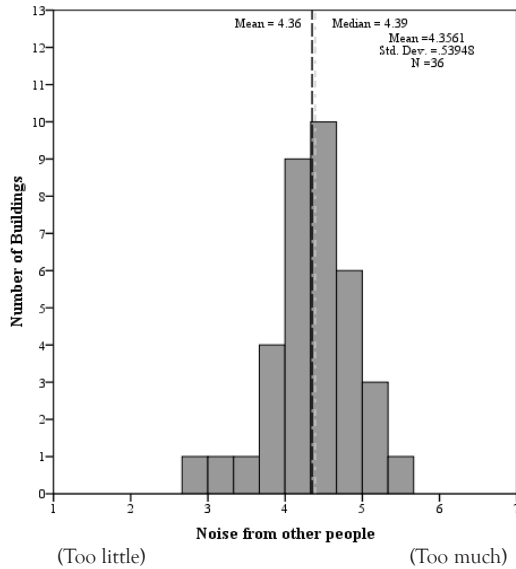


Figure 3. Distribution of 'noise from Other People'

Figure 4. Distribution of 'other noise from Inside'

building, integrating all relevant factors and based on experience of the building in use over a reasonably long term (over a year in 75 per cent of cases).

The sample mean and median scores (4.40 and 4.48 respectively) are similar and indicated by the vertical dashed lines. With an SD of 0.77 the spread of the scores is relatively wide, with 26 of the 36 buildings (or 72%) scoring above the mid-point of the scale.

Noise from Colleagues

Figure 2 shows the distribution of the mean scores for each of the buildings in the sample, in terms of the users' perceptions about noise from *Colleagues*.

The reference here is to noise emanating from the people in the occupant's work group or team and located in the immediate vicinity of their work area, whether open plan or cellular. While this category of noise can take many forms, occupants are being asked to make a judgement call on a spectrum

ranging from too little to too much.

Again, the mean and median (4.35 and 4.42 respectively) for this factor are very similar, but with a smaller SD of 0.42 the mean scores for each building are clustered around the mid-point of the 7-point scale – an encouraging result given a value of '4' is the ideal score in this case. However, most of the buildings (29 out of the 36, or 81%) have mean scores greater than 4 indicating a perception of there being too much noise from *Colleagues*.

Noise from Other People

Figure 3 shows the distribution of the mean scores for each of the buildings in the sample, in terms of the users' perceptions about noise from *Other People*. Depending on the layout and planning of the building, other people could range from members of nearby work groups (above, below, or in adjacent spaces) to visitors, cleaners and maintenance personnel.

Once again, the mean and median are similar to each other and to the noise from *Colleagues* scores. While the SD is slightly larger, the same number of buildings (81%) have mean scores greater than 4 indicating a perception of there being *too much* noise from *Others* on average.

Other Noise from Inside

Figure 4 shows the distribution of the mean scores for each of the buildings in the sample, in terms of the users' perceptions of other noise from *Inside*. Examples of this type of noise include that from nearby photocopiers and printers, kitchen areas, footfalls on hard surface walkways, door operation, and the like.

A very similar pattern is evident here too. Interestingly there is one building where there it appears the users perceive there to be *too little* other noise from inside. However, in most cases (69% of the buildings have average scores greater than 4) the average perception is that there is *too much*.

Noise from Outside

Figure 5 shows the distribution of the mean scores for each of the buildings in the sample, in terms of the users' perceptions about noise from *Outside*. This category refers to sources of noise external to the building, ranging from nearby traffic and open-air performances, to distant industrial and agricultural operations.

Here too, the mean and median (3.86 and 4.04 respectively) are similar, but in

Table 2. Correlation between *Noise Overall* and selected performance factors (R=Pearson Correlation Coefficient)

Strong (R between 0.6 & 0.8) [16]	R
Productivity	0.774
Overall Comfort	0.763
Building Design	0.691
Perceived Control over Noise	0.655
Needs	0.625
Moderate (R between 0.4 & 0.6) [16]	
Health	0.573
Space in building	0.568
Facilities	0.556
Image	0.521
Availability of Meeting Rooms	0.497

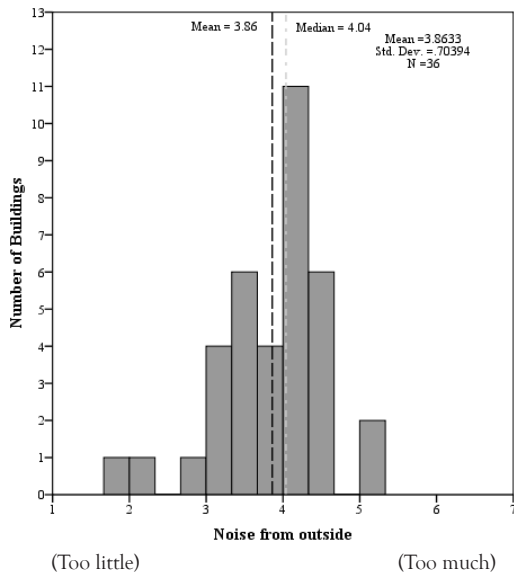


Figure 5. Distribution of ‘noise from Outside’ scores

this case the numbers of buildings on each side of the mid-point value of 4 are about the same. While there were a few cases with very low scores, indicating the occupants felt there was too little noise from outside; and a few at the other extreme; most (31 out of 36, or 86%) lay in a central band, between 3 and 5.

Correlation of Noise Overall with other factors

As noted earlier, the survey involved asking respondents to rank their perception of a range of performance factors (some 45 all told) of which the acoustical set comprised the five previously outlined. It was therefore of interest to test for correlations between some of these to gauge the influence of acoustic factors.

Some ten factors were selected for

testing against the acoustical factor *Noise Overall*. Of these, five turned out to have strong, and five to have moderate correlations with *Noise Overall* as shown in Table 2.

As can be seen, *Productivity* and *Overall Comfort* had by far the strongest association with *Noise Overall*, with Pearson Correlation Coefficients (R) of 0.774 and 0.763 respectively.

In the case of *Productivity*, the question posed was ‘Please estimate how you think your productivity at work is decreased or increased by the environmental conditions in the building?’ Occupants indicated their response on a scale ranging from ‘-40% or less’ to ‘+40% or more’ with 10% intervals.

The line of best fit and 95% confidence

Table 3. Median scores comparison of Conventional, Green-intent, and Sustainable buildings

Noise Factor	Conventional	Green-intent	Sustainable	Ideal
Overall	4.23	4.22	4.48	7
Colleagues	4.35	4.33	4.42	4
Others	4.35	4.40	4.39	4
Inside	4.10	4.30	4.25	4
Outside	3.75	3.75	4.04	4

Table 4. Mean scores for a range of environmental factors

Environmental Factor	Mean Score
Lighting Overall	5.15
Overall Comfort	4.91
Thermal Conditions in Winter	4.44
Noise Overall	4.40
Thermal Conditions in Summer	4.33

limits for this relationship are plotted in Figure 7, the R squared linear value of 0.599 (being the square of the correlation coefficient) signifying that it accounts for around 60% of the variance between these two factors.

In the case of *Overall Comfort*, the question posed was ‘All things considered, how do you rate the overall comfort of the building environment?’ with occupants indicating their responses on a 7-point scale ranging from ‘Unsatisfactory’ to ‘Satisfactory’.

The line of best fit and 95% confidence limits for this relationship are plotted in Figure 8, the R squared linear value of 0.583 (being the square of the correlation coefficient) signifying that it accounts for around 58% of the variance

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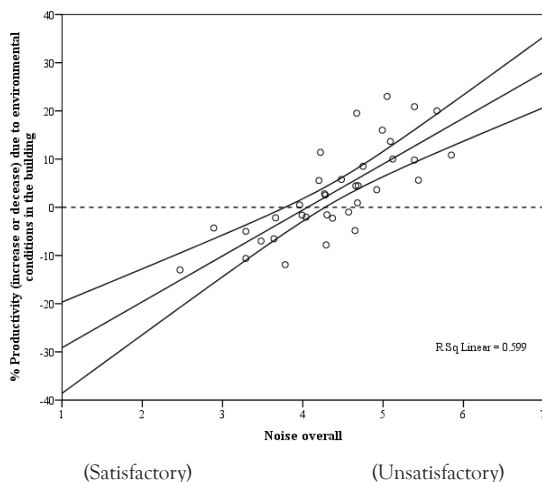


Figure 7. Plot of perceived *Productivity* vs *Noise Overall*

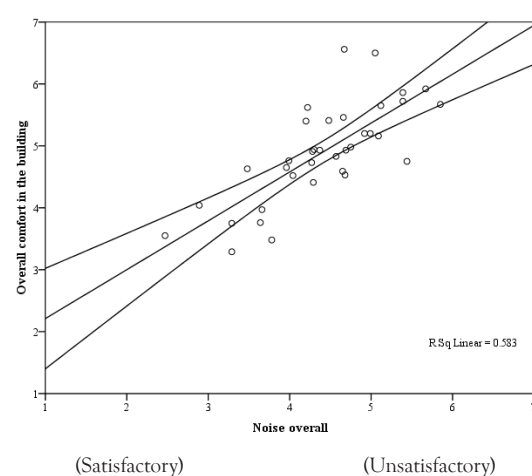


Figure 8. Plot of perceived *Overall Comfort* vs *Noise Overall*

between these two factors.

Discussion and Conclusions

On the face of it, achieving a mean score of 4.40 for Noise Overall, on a 7-point scale on which a '7' would be the ideal, does not appear to be particularly laudable. Nevertheless, not only is it on the 'better' side of the mid-point of the scale, it is also 'better' than the benchmark score of 4.17 (the average of the previous 50 buildings surveyed). It is also better than the average of a larger set of both conventional and green-intent buildings (see Table 3 later).

As noted on Figure 1, the individual building means cover a wide range of values, but the majority (some 72% of the sample of 36 buildings) score above the mid-point of the range, 18 of them between 4 and 5, and a further 8 between 5 and 6.

A recent analysis by Leaman and Bordass [17] on a larger data set of 165 buildings in the UK, which included both conventional and in their parlance, 'green-intent' buildings reported the median scores for several of these variables. Table 3 compares the median noise scores for these buildings with our set of sustainable buildings.

As can be seen, the 'sustainable' buildings set scores higher than both the 'conventional' and the 'green-intent' buildings for *Noise Overall*, with an average value of 4.48 (cf 4.23 and 4.22). Given this factor is rated on a 7-point scale where a score of 7 would be the ideal, the implication is that the sustainable set is performing better.

In the case of the three factors concerned with internal noise issues, where a score of 4 would be the ideal (ie. noise from *Colleagues*, *Others*, and *Inside*) the differences are small, though with the suggestion of slightly more noise from colleagues. All of these scores were greater than 4, indicating a perception that on average there is too much noise in these buildings. The average perception score for noise from *Outside* is close to the ideal of 4.

Table 4 ranks the mean scores for a number of 'overall' environmental factors, for all of which a score of '7' would be the ideal, in descending order. As can be seen, by comparison with

these other factors, *Noise Overall* lags well behind *Lighting Overall* in the occupants' perceptions but is comparable with thermal conditions in winter and summer. *Overall Comfort* (which can be considered as the integrated perception of all the environmental factors) is towards the higher end of the range with an average score of 4.91. Clearly, some effort will be needed to achieve perception scores for noise that are on a par with those for lighting.

These findings concur with those of Jensen, Arens and Zagreus [18] of the Center for the Built Environment, University of California, Berkeley, who used the alternative approved survey methodology [19] noted in the Introduction. They concluded inter alia, following a survey of 142 buildings, that "Overall, of the nine core satisfaction categories in the IEQ [Indoor Environmental Quality] survey, poor acoustics cause the greatest dissatisfaction".

While the sustainable buildings of the present survey appeared to perform a little better than conventional buildings there is still plenty of room for improvement. Paevere [20] lists several "Opportunities for improving acoustic environment" in a recent review of indoor environmental quality and occupant productivity in office buildings. These should be a high priority for the designers and operators of sustainable buildings. The strong correlations indicated in Figures 7 and 8 indicate that improvements in the users' perceptions of noise could result in significant improvements in overall comfort and productivity.

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