USERS' PERCEPTIONS OF HEALTH AND PRODUCTIVITY IN SUSTAINABLE BUILDINGS

George Baird and Hedda Oosterhof

Summary of

Actions Towards Sustainable Outcomes

Environmental Issues/Principal Impacts

- For workplaces such as offices, green buildings have been said to lead to increased productivity and occupants have reported feeling more healthy.
- As 'green' buildings are becoming more mainstream there is increasing commercial pressure to quantify their benefits.
- Showing measurable increases in productivity or occupant health will potentially aid designers in the procurement of greener buildings.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- Sustainable buildings are having a positive influence on their occupants' perception of their health and productivity.
- Very strong correlations have been found between the occupants' perceptions of health, productivity, overall environmental comfort, and space in the building as a whole.

Cutting EDGe Strategies

- Designers and their clients should be prepared to test a range of design features in the expectation that not all design strategies will be successful.
- Owners must be prepared to put significant effort into the management of sustainable buildings, including keeping the tenant organisations and individual occupants familiar with its options and opportunities for achieving optimum conditions. As well, constraints in terms of internal layout need to be discussed so the occupants do not furnish or partition the layout in ignorance of how this will affect the building's performance, and user comfort.
- Mixed-mode heating, ventilation and air-conditioning systems, in which the mechanical systems only operate under adverse climatic conditions, with natural ventilation and passive heating and cooling used when outside conditions are appropriate, have been employed in many of the better performing buildings.

Synergies and References

- George Baird, 2010, *Sustainable Buildings in Practice – What the Users Think*, Routledge, UK. This book is by the paper's author, and presents an unbiased evaluation of 30 of the most cutting edge sustainable buildings in the world, in terms of the users' perceived comfort, health and productivity.
- Leaman, A, and Bordass, B, 2007, 'Are Users More Tolerant of 'Green' Buildings', *Building Research and Information*, 35, 6, 662-673. This article makes a statistical comparison between conventional and sustainable buildings, based on occupant surveys of 177 buildings in the UK.
- *Environment Design Guide*
  - GEN 67: Green Buildings and Productivity
  - GEN 79: Impact of Indoor Environment Quality on Occupant Productivity and Wellbeing in Office Buildings
  - TEC 22: Indoor Environment Quality, Design, and Facility Ecology Worth

ENVIRONMENT DESIGN GUIDE

USERS' PERCEPTIONS OF HEALTH AND PRODUCTIVITY IN SUSTAINABLE BUILDINGS

George Baird and Hedda Oosterhoff

Users of a range of commercial and institutional buildings in eleven countries have been surveyed to understand their perceptions of the performance of a range of factors – operational, environmental, personal control, and satisfaction with the latter including health. All the buildings in question have received national awards for sustainable design or have scored well in terms of their respective country's building sustainability rating tool. This paper focuses on how the users perceived these buildings to be affecting their health, both in terms of their qualitative rating of that effect and their written comments on that aspect of the study.

Based on respondents' ratings (or scores) of the health and productivity perceptions it was found that, on average, these 'sustainable' buildings were perceived to be healthier than a data-set of 'conventional' buildings. A very strong correlation was found between health and productivity and interesting correlations were found between the respondents' scores and their comments.

Keywords:
health, green buildings, sustainable buildings, Post Occupancy Evaluation (POE), rating tool, users' perceptions

Figure 1 Atrium of 60 L, Melbourne

Looking up into one of the thermal chimneys from the atrium of 60 Leicester Street in the city fringe suburb of Carlton. These are used to promote natural ventilation of the building under appropriate climatic conditions.

(Source: George Baird, 2005)

1.0 INTRODUCTION

Background

Not long ago one of the major concerns of building researchers and building users was sick building syndrome (or SBS). In the 1980s, SBS was the term used for building-related sicknesses, which were perceived as affecting the health and productivity of the building users. Research teams around the world administered questionnaires of varying size and complexity to the occupants of what were usually commercial offices to measure the environmental conditions in typical work spaces, and to deduce 'cause and effect' from the resulting mass of data.

The overall consensus seemed to lay blame for sick buildings on factors such as off-gassing products or particulates from building materials, high levels of bacteria, and fungal growth in humid conditions, all combined with low ventilation rates. The latter being blamed on the responses of over-zealous facilities

Figure 2 Rooftop of 60 Leicester Street, Carlton, Melbourne

Glazing of atrium in the foreground, one of four thermal chimneys dominating the shot.

(Source: George Baird, 2005)

managers, HVAC system designers, and ventilation standards writers to curb the escalating costs of the electricity to run the fans, following a succession of direct 'energy crises' (Kumar and Fisk, 2002).

More recently, in response to the more pervasive 'environmental crisis', building designers and developers have been producing more sustainable buildings for their more environmentally conscious clients. Are 'green' buildings resulting in healthy and creative facilities with stimulating work environments for their employees, or are they producing a new set of problems for the unsuspecting building occupant? In an attempt to answer this question, this paper investigates the performance of a number of new generation green buildings.

One should be careful with the terminology 'sustainable' – we are sure that none of our current sustainable buildings would claim to have zero environmental impact, but rather that they are moving towards that goal. William Bordass and Adrian Leaman (2007) have coined the useful phrase 'green-intent' which encapsulates the concept.

Selected Projects
Australia
• 40 Albert Road, South Melbourne, Victoria
• '60L', Leicester Street, Carlton, Melbourne
• Red Centre and Institute of Languages, University of NSW, Sydney
• Student Centre and General Purposes Building, Newcastle University
• Scottsdale Forest Ecocentre, King Street, Scottsdale, Tasmania
Canada
• Computer Science and Engineering, York University; Liu Institute, University of British Columbia
• Toronto Military Families Resource Centre, National Engineering Yards, Vancouver
Germany
• Sciencepark, Gelsenkirchen
India
• Torrent Research Centre, Ahmedabad.
Ireland
• St Mary's Credit Union, Navan
Japan
• Nikken Sekkei HQ, Tokyo; Earthport, Yokohama
Malaysia
• Menara UMNO, Penang; MEWC HQ, Putrajaya
New Zealand
• AUT Akoranga, Auckland; Landcare Research, Auckland; Mathematics Statistics and Computer Science, Christchurch
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, Santa Monica, NRG Systems, Vermont

Table 1 Buildings surveyed

2.0 RESEARCH METHODS

2.1 Why Measure Perception?

We are firmly of the belief that people can provide one of the best measures of building performance, "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., 1996, for more explanation).

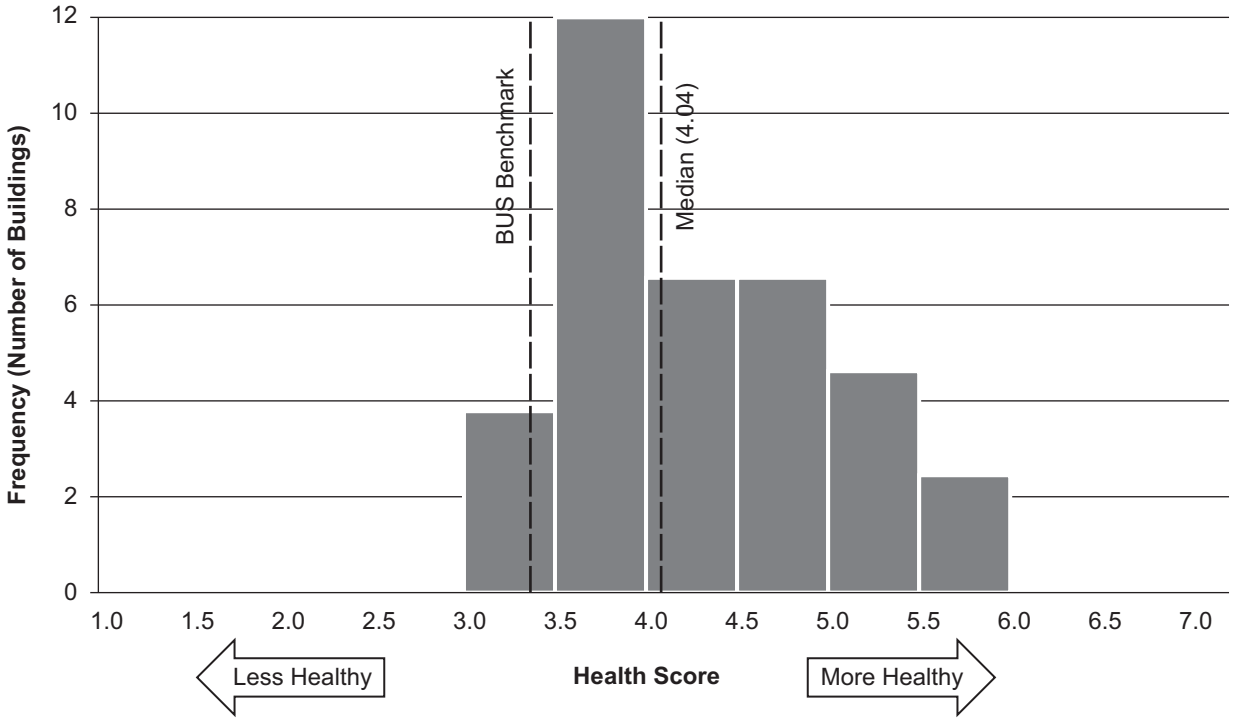


Figure 3 Frequency distribution of average health scores

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 context of office buildings, health is even more difficult to quantify as the SBS researchers discovered. In the case of productivity, Leaman and Bordass (2005) 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 Garry Raw (himself a lead SBS researcher) so aptly said "in buildings, people are the best measuring instruments: they are just harder to calibrate"".

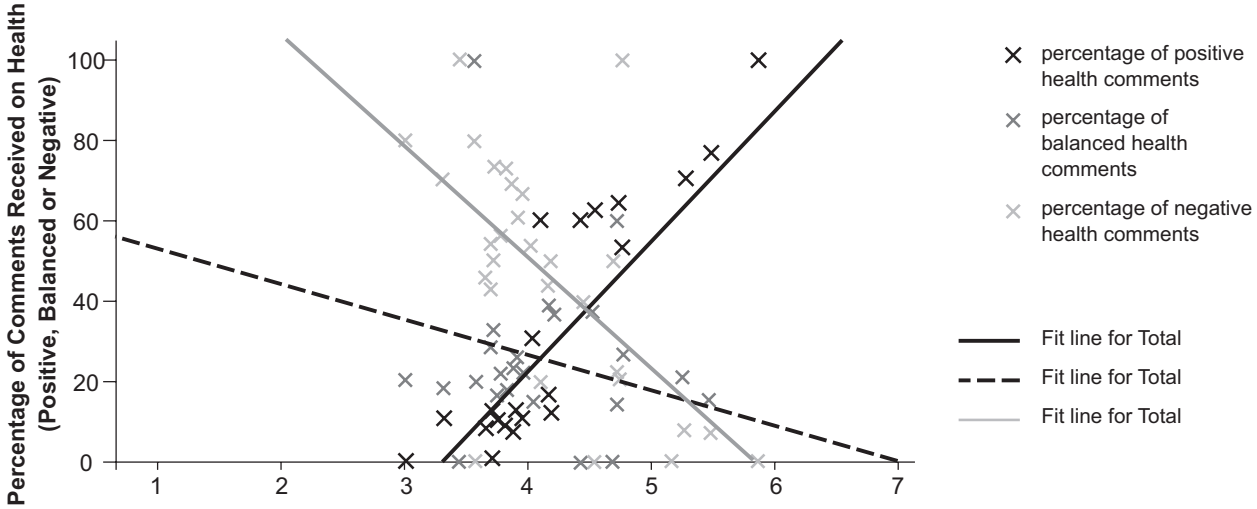


Figure 4 Health comments plotted against the average score for each building

This graph shows for each building its average rated health score on the x axis, and directly above this, three values for the percentage of positive, negative and balanced comments offered by users. The average building perceived health rating of 4 means occupants felt no more or less healthy in this building than normal. Interestingly the best fit lines for negative and positive comments show that for a building with this average health rating, one might expect over twice as many negative comments as positive.

Figure 5 Natural Resources Defence Council Building in Santa Monica, California

The Natural Resources Defence Council is a non-profit organisation whose mission is to protect public health and the environment. The original 1920's building, which was already well placed for public transport, was stripped back to its original wooden structure and fully renovated as a demonstration of sustainable design.

(Source: George Baird, 2005)

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

2.2 The Survey

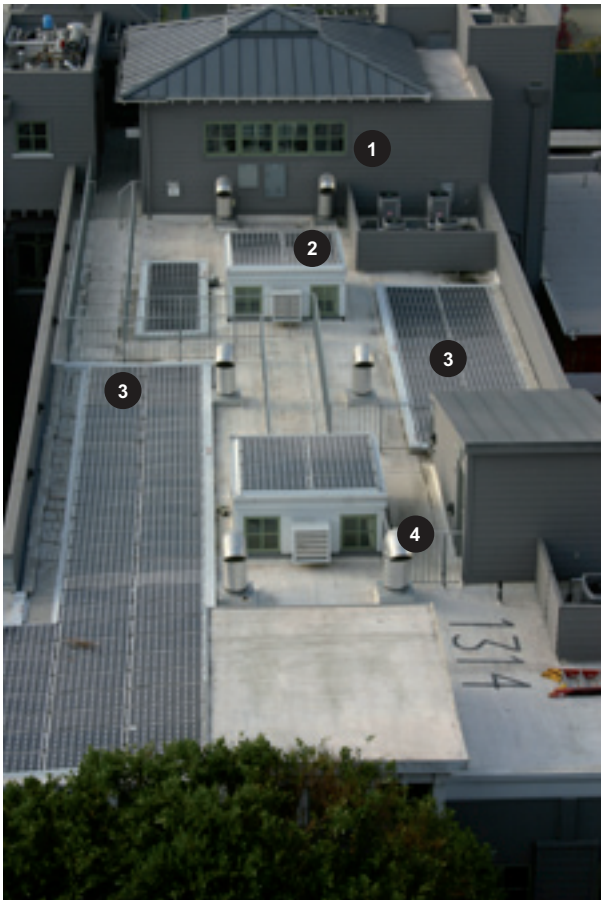
For the last four years the performance of around 40 commercial and institutional buildings in 11 countries worldwide has been investigated by one of the authors (George Baird, 2010). These investigations involved the principal author in one or more visits to each of the buildings and the personal distribution and collection of a questionnaire survey seeking the users' perceptions of a range of factors: operational, environmental, personal control and satisfaction. The assessment for satisfaction covered: design, needs, comfort overall, productivity, and health. We have found that personal distribution and collection of the questionnaires is by far the best way to maximise the response rate. A high rate of at least 80 per cent response from building occupants was achieved and even exceeded in all cases.

The questionnaire has evolved over several decades, from a 16-page format used for the investigation of sick building syndrome in the UK in the 1980s, to a more succinct 2-page version. Developed by Building Use Studies (BUS, 2004) for use in the Probe investigations (BRI, 2001/2), it is available under licence to other investigators, and is a widely accepted survey tool. Once collected, the data from the questionnaires was entered into pre-formatted spreadsheets provided by BUS. The results for individual buildings were sent to BUS for analysis, and the analysis of the data for the whole set of buildings was made by the authors. The powerful Statistical Package for the Social Sciences (SPSS) was used by the authors for this analysis.

For this paper, the authors focus on how the users perceived these buildings to be affecting their health, both in terms of their quantitative rating of that effect on the seven-point scale, and their written comments which were categorised as being either positive, balanced or negative. Statistical analysis was used to find the level of association that existed between the occupants' perception of health and some of the other key factors that were assessed, in particular their perceived productivity (see Section 5 later).

3.0 THE BUILDINGS SURVEYED

The buildings surveyed were as listed in Table 1 below. 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 countries'



1. Naturally ventilated conference room added to roof
2. Clerestories provide both daylight and natural ventilation
3. Photovoltaic panels added to roof deck
4. Fresh air intakes added to ventilate building interior

Figure 6 Rooftop of the Natural Resources Defence Council Building in Santa Monica, California

The new flat roof incorporates many ESD features.

(Source: George Baird, 2005)

1. Solar hot water heaters
2. Roof mounted PV collectors
3. High level windows admit natural light to the workspace and have automatic motorised internal louvres that limit glare, and can reflect light up onto the ceiling
4. Operable windows
5. Free-standing PV collectors follow the sun by a mechanism that uses the expansion of a volatile fluid when heated by the sun, to power the movement.

Figure 7 NRG Systems headquarters, Hinesburg, North Vermont, USA

This company whose business is related to wind energy assessment has shown its strong commitment to renewable energy by experimenting with three forms of photovoltaic cells and multiple ESD building features included on the southern façade of the company headquarters.

(Source: George Baird, 2005)

building sustainability rating tool such as LEED, BREEAM, CASBEE, Green Star, Green Globes, etc. (see Cole, 2005 and 2006 for reviews) 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 were willing to participate in the study.

Over 2000 staff responded to the questionnaire, the vast majority scoring every question. The numbers ranged from a low of 13 responses (the small staff group at the Toronto Military Families Resource Centre) to a high of 334 at London City Hall, with a mean of approximately 66 respondents per building. Given this range, the resulting data was scrutinised carefully to ensure they did not bias the analysis.

While most of the buildings were in temperate climates of one kind or another, ranging from warm-temperate to cold-temperate, a significant number were located in warm-humid climates. Their systems of ventilation ranged from full air-conditioning, through mixed-mode (concurrent, changeover and zoned) to both conventional and advanced natural ventilation.

4.0 PERCEPTIONS OF HEALTH

The 'health' question on the survey form was couched in the following terms: "Do you feel less or more healthy when you are in the building?", with the guidance footnote "please try to evaluate this building with respect to your experience of using buildings in general." The occupants were asked to indicate their response on a seven-point scale ranging from 'less healthy' to 'more healthy'. Immediately under this was a box where respondents were invited, should they wish, to write any "Comments about health".

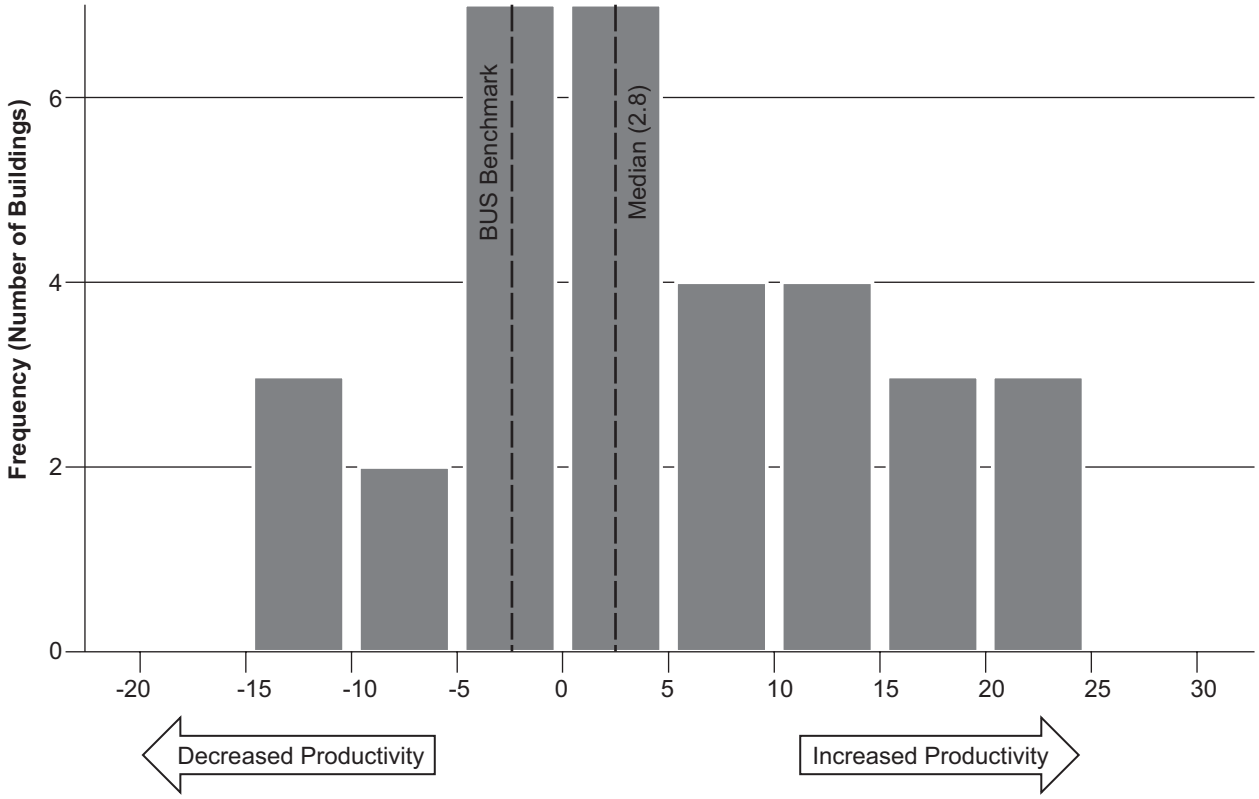


Figure 8 Productivity perception ratings for the whole sample group of buildings

This graph groups responses of increased or decreased perceptions of productivity into bands of five per cent either side of the mean rating of zero. The median of 2.8 per cent and the mean of 4.2 per cent in this study show the occupants felt more productive in these buildings as a whole.

Mean – The type of average where a series of results are added together and the total is divided by the number of scores.

Skew – the quality of a distribution that defines the disproportionate frequency of certain scores. If there are a few uncharacteristically high or low results, these can 'skew' the value of the mean so that it is not indicative of the main body of results. Thus the value of the median.

Median – the point at which 50 per cent of the cases in a distribution fall below and 50 per cent fall above. In a normal distribution (bell curve) the mean and the median would be the same, both sitting at the centre of the curve, however where there are uncharacteristically high or low results that 'skew' the mean, the median may give a more true indication of the main body of results.

N – is the number of scores in the given study.

Standard Deviation – is the average deviation from the mean. For example, if this value is 0 then all the values are the same. A low standard deviation will mean results are generally bunched closer to the mean, whereas with a high standard deviation the results will be more disparate.

Frequency Distribution – a method for illustrating the distribution of scores within intervals of a set measure (for example, grouping the results in 5 per cent bands either side of the mean as seen in Figure 3).

Variance – the square of the standard deviation, and another measure of a distribution's spread or dispersion.

Correlation Coefficient – or 'r value' is a numerical index that reflects the degree of correlation between two variables. A value of 1 or -1 being perfect correlation, and a value of zero indicates an absence of any correlation.

Line of Best Fit – the regression line that best fits the actual scores and minimises the error of prediction. This line is a straight line that 'best fits' between a range of results, and thus indicates the trend of the results.

R Squared Linear – is the square of the correlation coefficient. This indicates the percentage variance that the body of results has from the line of best fit.

Box 1 Statistical Terminology

(Source: adapted from Salkind, 2005)

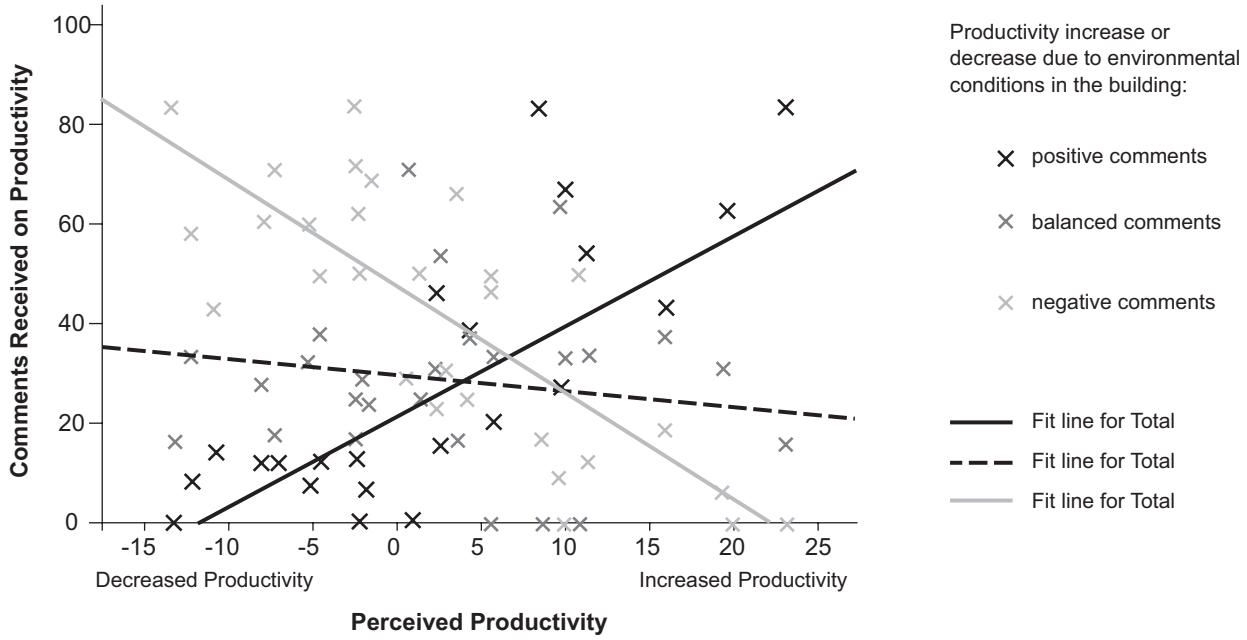


Figure 9 Plots of productivity comments rate versus average scores for each building

4.1 Health Scores on the Seven-point Scale

Figure 3 shows the distribution of the average health scores for each building. The mean value for rating of perceived health for this group of sustainable buildings is 4.25. If one considers the scale mid-point value of 4.00 as the 'break-even' score, this result indicates that on average the occupants judge these buildings to be marginally more healthy.

The mean value of 4.25 for these buildings may be compared to the Building Use Studies (BUS) benchmark figure which is based on the preceding 50 buildings surveyed by BUS and their licensees. The mean varied slightly over the duration of the research project, ranging from 3.3 to 3.6. Evidently, the average person feels less healthy in the average building. In that context, the buildings studied are perceived as a significant improvement with all but three rating better than the benchmark, and more than half of them scoring higher than the scale mid-point.

A recent analysis by Bordass and Leaman (2007) on a larger data set of 165 buildings in the UK, which included both conventional and, in their phraseology, 'green-intent' buildings, found that twenty-five per cent of buildings have health scores greater than 4, the scale mid-point. When the data set was broken down into these two categories, 'conventional' and 'green-intent', analysis of variance indicated their mean values were significantly different. The median score for the 'conventional' buildings was around 3.2, while that for 'green-intent' buildings was approximately 3.7. The median value for the sustainable buildings in the author's 'worldwide' data set is even higher, at 4.04, an encouraging trend.

4.2 Occupants' Comments on Health

Not all occupants chose to make comments on the health aspect of their buildings, although on average about 23 per cent did. In terms of the nature of their responses, the comments were placed into three

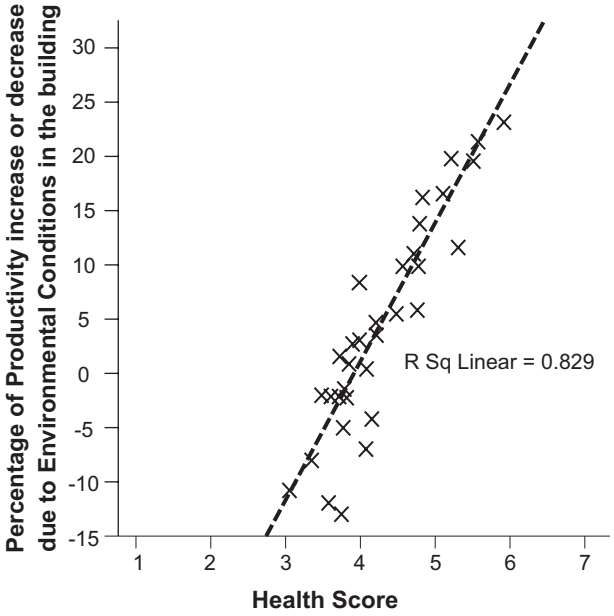


Figure 10 The correlation of perceived productivity versus that of health

Of the ten factors assessed against health, productivity had the highest correlation coefficient of 0.910. The square of this is 0.829, the 'R Sq Linear' value noted on the graph. This indicates that 82.9 per cent of the variance in productivity can be explained by the variance in health, and vice-versa.

VERY STRONG CORRELATION	
productivity	0.910
building design	0.869
comfort overall	0.855
space in the building	0.822
STRONG CORRELATION	
summertime conditions	0.752
summer temperatures	0.684
wintertime conditions	0.671
lighting overall	0.625
noise overall	0.616
MODERATE CORRELATION	
winter temperatures	0.589

Table 2 Correlation of other factors of perception relative to those of health

categories:

- positive – around 25 per cent extolled the virtues of the building, health-wise
- negative – 50 per cent noting health problems they attributed to the building
- balanced – 25 per cent were neutral about the effect of the building on their health, or made a combination of positive and negative comments

These findings may be contrasted with mean score of 4.25 for these buildings, and to which all the occupants contributed. Clearly, the comments from the 23 per cent of occupants who were prepared to make them tended to be negative.

Given that not all respondents ventured a comment, it was of interest to see if there was any inherent bias or correlation between the nature of the comments and the scores. Figure 4 plots the positive, negative and balanced comments for each building against the scores, expressed as a percentage of the total number of 'health' comments received for that building. The line of best fit and 95 per cent confidence limits for each case are also indicated. It is reassuring to note that the positive and negative comments trends are as one would have anticipated (i.e. the scores increase as the proportion of positive comments increases, and the scores decrease as the proportion of negative comments increases), while a good number of the balanced comments are clustered around 4.00 the mid-point of the scale.

The graph in Figure 10 plots the average perceived increase or decrease in productivity versus health, with a straight line fitted to indicate the overall trend.

5.0 PERCEPTIONS OF PRODUCTIVITY

The 'Productivity at Work' question asked respondents to "Please estimate how you think your productivity at work is decreased or increased by the environmental conditions in the building?" Figure 8 shows the distribution of the average percentage productivity for these buildings. The mid-point value of 0 per cent may be considered to imply that the building is 'neutral' in terms of its effect on the respondents' perception of their productivity. In fact, the mean value for this sample is +4.18 per cent, which indicates that on average the occupants perceive themselves to be more productive in these sustainable buildings. In comparison, the BUS benchmark mean hovered between 0 and -5 per cent during the period of these surveys. By that measure, 21 of the subject sustainable buildings were perceived to have higher productivity, 5 lower, and 7 about the same as this benchmark.

Similarly to health, approximately 26 per cent of respondents commented on productivity as well as scoring it. Figure 9 plots the positive, balanced and negative, comments on productivity versus the corresponding scores for productivity in each building. Again, a good percentage of the variance is explained by the lines of best fit for comments of a positive and a negative nature (63.1 per cent and 45.2 per cent respectively).

6.0 CORRELATION OF HEALTH WITH OTHER VARIABLES

Previous studies (BRI, 2001/2) had indicated strong correlations existed between such factors as perceived productivity and perceived overall comfort scores. However in this study, the scores for health and a number of other factors were also tested to determine how strongly they were correlated for this group of sustainable buildings. Broadly speaking, a correlation coefficient in the ranges 0.8 to 1.0 shows a very strong correlation, 0.6 to 0.8 strong, and 0.4 to 0.6 a moderate relationship (Salkind, 2005:88). Of the ten factors assessed against health, productivity had the highest correlation.

7.0 CONCLUSION

With a median value of 4.04, just over half of the cases surveyed were perceived to be on the 'more healthy' side of the scale mid-point of 4.00, which on face value is not an especially encouraging result. However, when one considers that the BUS median score for conventional buildings was only 3.2 it is clear that these results from our data set of sustainable buildings imply a considerable improvement in users' perception of health has been achieved by the 'green' buildings studied.

Negative comments on health outnumbered positive by 2 to 1, confirming what every facility manager knows – the propensity of building occupants to complain rather than praise. Given the greater likelihood for negative feedback it was, however, reassuring to see a good correlation between the perception scores and the comments for both health and productivity. As one would have anticipated, the health scores increased as the proportion of positive comments increased, and likewise, the scores decreased as the proportion of negative comments increased. Interestingly, it seemed

that it was only necessary to have around 20 per cent of positive comments in order to reach the mid-point of the health and productivity scales.

The distribution of the productivity perception scores was considerably more positively skewed than that for health with the result that some 64 per cent of these 'green-intent' buildings indicated productivity increases. Again, there was good correlation between the scores and the negative and positive comments for productivity with a ratio again of two to one, though there were more 'balanced' comments on productivity (32 per cent) than in the case of health (25 per cent).

Of the individual factors tested for their correlation with health, productivity was by far the strongest, closely followed by building design, comfort overall, and perception of the space in the building as a whole. While it is not feasible to ascribe cause and effect, there seems little doubt that these factors are closely associated with one another.

It is anticipated that future analyses by the lead author of this paper and his research assistants will give further insights into the nature of these and other relationships that have a significant impact on the health of the building users. These may also give further credence to the assertion of facilities management commentator Sunil Shah that "Results of hundreds of studies and reports have demonstrated a significant and causal correlation between improving the indoor environment and gains in productivity and health" (Shah, 2007, p222).

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge Adrian Leaman for permission to use the Building Use Studies questionnaire under licence. Thanks are also due to Jessica Ferris who provided research assistance and to Victoria University of Wellington for funding assistance. The authors also thank all the building owners and occupants for their responses.

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BIOGRAPHY

Dr George Baird is Professor of Building Science in the School of Architecture, Victoria University of Wellington, New Zealand.

Email: George.Baird@vuw.ac.nz

Hedda Oosterhoff was a Research Assistant and is now a Graduate of the School of Architecture, also at Victoria University of Wellington.

APPENDIX – USER SURVEY

Questionarie

As noted in Section 2.2, the questionnaire has evolved over several decades, from a 16-page format used for the investigation of sick building syndrome in the UK in the 1980s, to a more succinct 2-page version. Developed by Building Use Studies (BUS, 2004) for use in the Probe investigations (BRI, 2001/2), it is available under license to other investigators.

The sixty or so questions cover a range of issues. Fifteen of these elicit definitive background information on matters such as the age and sex and location of the respondent, how long they normally spend in the building, and whether or not they see personal control of their environmental conditions as important. However, the vast majority of questions in the survey ask the respondent to score their perceptions of some aspect of the building on a seven-point scale; typically from 'unsatisfactory' to 'satisfactory' or 'uncomfortable' to 'comfortable', where generally a '7' would be the best score.

The BUS survey used in this study covers the following aspects:

- Operational (7 questions) - space needs, furniture, cleaning, meeting room availability, storage arrangements, facilities, and image
- Environmental (28 questions) – various aspects of temperature and air quality (4 questions each) in different climatic seasons (summer and winter in most cases), lighting (5 questions), noise (6 questions), and comfort overall
- Personal Control (5 questions) – of heating, cooling, ventilation, lighting, and noise
- Satisfaction (5 questions) – design, needs, comfort overall, productivity, and health.

Analysis of the responses yields a mean value (on a 7-point scale) for each variable. In addition to calculating these mean values, the analysis also enables the computation of a number of ratings and indices in an attempt to provide indicators of particular aspects of the performance of the building or of its 'overall' performance.