BEDP ENVIRONMENT DESIGN GUIDE

IMPACT OF INDOOR ENVIRONMENT QUALITY ON OCCUPANT PRODUCTIVITY AND WELL-BEING IN OFFICE BUILDINGS

Phillip J Paevere

Summary of

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

- Good IEQ can have a positive impact on occupant health, well-being and productivity on both individual and organisational levels. Conversely, poor IEQ can have a significant negative impact.
- Provision of good IEQ is becoming increasingly important for other reasons as well, such as minimising compliance costs of future regulations related to IEQ, attribution of 'points' toward higher sustainability ratings, presenting a positive organisational image and encouraging worker attraction and retention.
- Good IEQ is a necessary, but not sufficient prerequisite for enhanced productivity, as other factors can also have a significant impact.

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:

- Establish appropriate thermal comfort criteria, and ensure these can be monitored and maintained over time.
- Establish criteria for noise levels and speech intelligibility – identify unwanted noise sources, and isolate, separate and mask them where possible.
- Establish task-specific and general criteria for illumination and glare – integrate natural and electric lighting strategies; incorporate user control over lighting and glare where possible.
- Identify and establish air quality criteria – eliminate, isolate, and minimise toxins and odour sources where possible.
- Incorporate workspace flexibility which provides for multiple spatial configurations, and for rapid and easy change to meet the needs of changing work tasks over time.
- Ensure maximum flexibility for delivering electricity, voice and data – incorporate mobile and wireless technologies that support new work styles and work practices.
- Actively seek occupant feedback on IEQ during commissioning, and act on it in a timely manner.

Cutting EDGe Strategies

- Incorporate productivity enhancing features that minimise occupant discomforts and distractions, encourage communication, and enable choice and control by building users over the physical characteristics of the environment.
- Allow for the ongoing incorporation of occupant feedback on IEQ into control, operation and maintenance strategies.

Synergies and References

- *BEDP Environment Design Guide:* GEN 67: Green Buildings and Productivity
- *BEDP Environment Design Guide:* TEC 22: Indoor Environment Quality, Design, and the Value of Facility Ecology
- Brown, SK, 2008, Design guidelines for Delivering High Quality Indoor Environments, Report No. 2003-028-B-01, CRC for Construction Innovation, Brisbane.

BEDP ENVIRONMENT DESIGN GUIDE

IMPACT OF INDOOR ENVIRONMENT QUALITY ON OCCUPANT PRODUCTIVITY AND WELL-BEING IN OFFICE BUILDINGS

Phillip J Paevere

Good Indoor Environment Quality (IEQ) can have a positive impact on the health, wellbeing and productivity of occupants in office buildings. Productivity benefits can potentially be financial as well as intangible in nature, and can be realised at both individual and organisational levels. This paper discusses key aspects of IEQ, in the context of occupant health and productivity, and outlines some specific strategies to assist in delivering high quality indoor environments. It should be noted that good IEQ is a necessary, but not sufficient pre-requisite for enhanced productivity, since other factors, specific to individual contexts, and not directly related to IEQ, can also have a significant impact.

Keywords
IEQ, indoor environment quality, productivity

1.0 INTRODUCTION

Indoor environment quality (IEQ) is a generic term used to describe the physical and perceptual attributes of indoor spaces. In the context of office buildings, these include the indoor air quality and the thermal, acoustic and visual properties of the environment, as well as various characteristics of the furnishings, facilities and fit-out (e.g. workstation design and space layout).

Good IEQ in a commercial office building can deliver wide-reaching real and potential benefits to occupants, employers and building owners. Benefits can be commercial in nature as well as intangible, and include:

- improved individual and organisational productivity
- reduced illness and absenteeism
- worker retention and attraction
- reduced operational and maintenance costs
- lower insurance costs, compliance costs and legal risks
- improved organisational image and marketing potential.

Given that people spend much of their time indoors (see Figure 1), the characteristics of a building's interior spaces have the potential to impact on the health, well-being and comfort of building occupants, which in turn may impact on their productivity while at work. Features of building interiors that enhance productivity include those that reduce discomforts and distractions, as well as those that enable more choice and control over the environment. Occupant productivity is a key driver in the business case for providing high quality interior environments, since salary costs make up such a large proportion of overall business costs (See Figure 2), and so even small improvements in productivity can result in significant bottom-line business benefits.

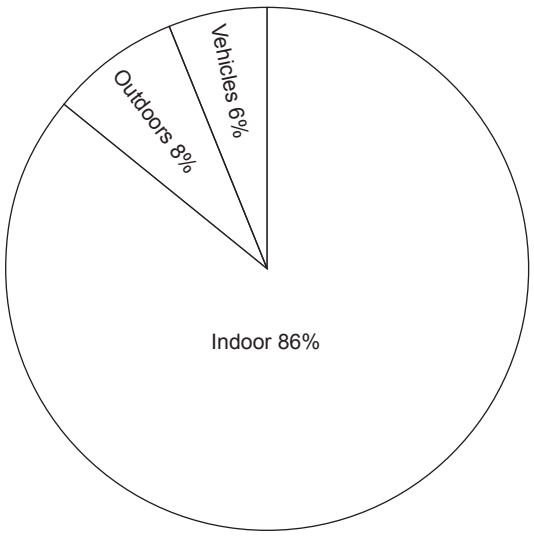

Figure 1. Breakdown of human activity by location

(Derived from: The US National Human Activity Pattern Survey (Klepeis et al. 2001))

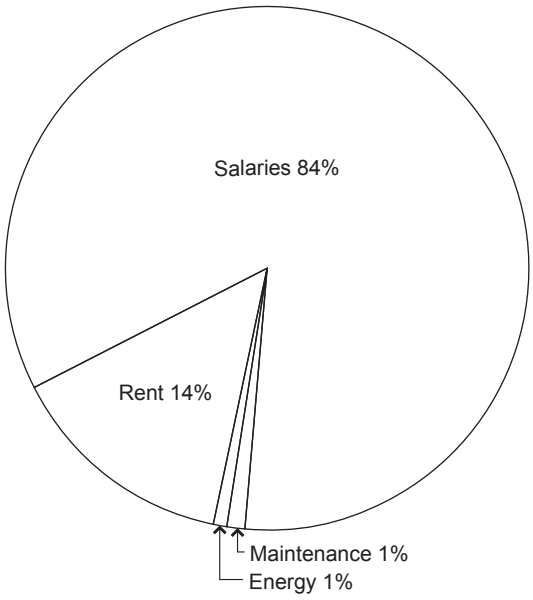

Figure 2. Breakdown of typical business costs

(Derived from: Browning and Romm, 1994)

One of the key challenges in assessing the link between enhanced occupant productivity, IEQ, and building and fit-out design, is being able to define and measure both good IEQ and productivity in meaningful terms. This can be complex because productivity indicators are highly specific to an organisation's context and business goals, and the definition of 'good' IEQ is highly dependant on qualitative factors such as occupant satisfaction.

This note provides a broad overview of relevant information about IEQ in office buildings, and the potential impact on occupant health, well-being and productivity, and provides some practical guidance for improving the indoor environment for enhanced occupant productivity.

2.0 IEQ AND PRODUCTIVITY IN BUILDINGS

2.1 Productivity Assessment

One of the key challenges in assessing the link between enhanced productivity and improvements in IEQ, is being able to define and measure both productivity, and IEQ in meaningful terms. Defining productivity is not clear-cut, because productivity indicators are highly specific to an organisation's context and business goals, and for an increasing proportion of creative and knowledge-based jobs, individual productivity may not necessarily be as important for business success, as is the productivity of larger units or teams. There are no absolute measures or indicators of productivity that are valid across and between organisations. However, in many studies which examine IEQ impact on productivity, self-assessed or perceived productivity is used as a practical relative indicator that can facilitate useful comparisons across different building environments and work contexts. More information on issues related to productivity definitions, models and assessment in buildings is given in Purdey (2005).

Occupant questionnaires conducted by Building Use Studies, with self-assessed ratings of productivity, show that the overall effect of buildings on occupant productivity can range from approximately a 20 per cent gain to a 15 per cent loss. However, most buildings fall into the +5 per cent to -5 per cent range, with about two-thirds having negative perceived productivity scores. It should be noted that this effect relates not only to IEQ variables, but to a range of other building issues, such as workspace design and facilities management response times, and that it is difficult to separate out the productivity impacts of IEQ and non-IEQ related issues (Leaman and Bordass, 2006).

From a practical perspective, productivity assessments are often conducted through 'before-and-after' case studies, where a building has been renovated, or occupants have moved premises, and assessments are made on either side of a change. In these analyses, it is important to check that there have not been any major shifts in non-building related influences on productivity, such as management and organisational change, staff morale and quality of information systems. Further information on non-building-related effects on worker performance is given in Purdey (2005). If it assumed that these non-building related factors can significantly influence productivity, it is important to obtain some before-and-after indicators of these, to be sure that the perceived productivity improvement is not swamped by any significant contextual shifts. As shown conceptually in Figure 3, it is quite feasible to obtain misleading results (i.e. 'false positive' or 'false negative') if these factors are ignored when assessing before-and-after productivity.

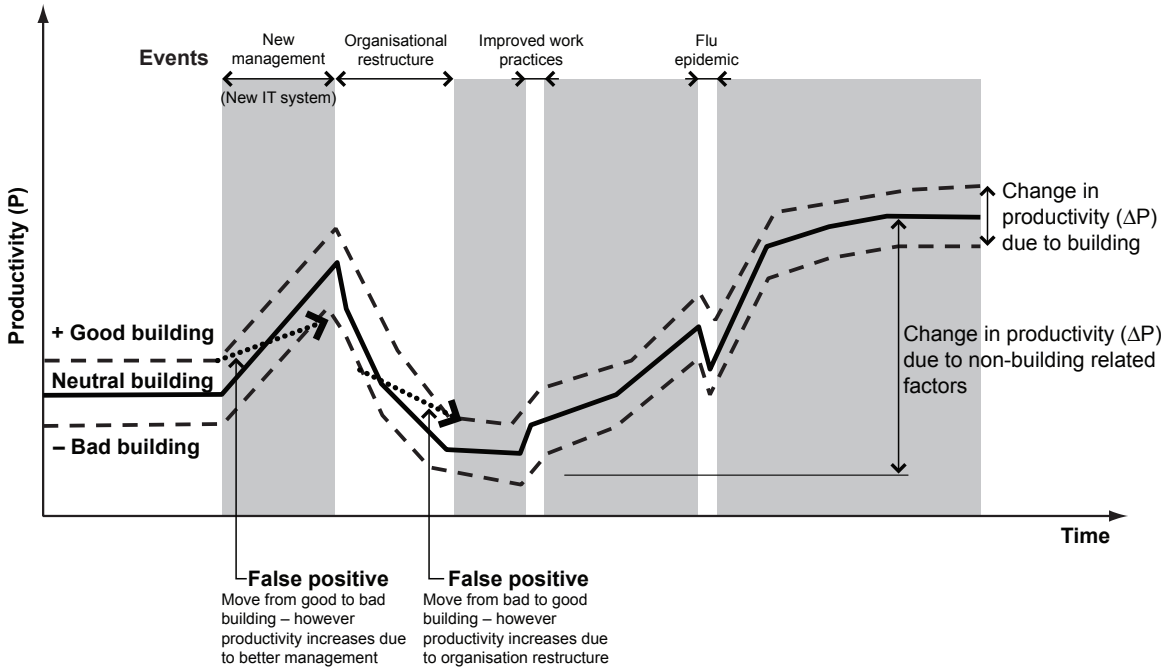

Figure 3. Conceptual diagram showing possible misleading effect of non-building factors on before-and-after productivity assessments

(Source: Paevere and Brown, 2008)

3.0 PRODUCTIVITY ENHANCERS IN BUILDINGS

Productivity enhancers include features that reduce discomforts and distractions, encourage communication, and enable choice and control over the physical characteristics of the environment. Key productivity enhancers in buildings include:

- good IEQ
- access to windows, daylight and sunlight where possible
- personal control over temperature, ventilation, lighting and noise where possible
- comfortable and adjustable furniture and equipment
- flexible workspace layout and design
- psychosocial features such as connection with nature and pleasing aesthetics
- opportunities for formal and informal social interaction between occupants.

3.1 Good IEQ

Although it is difficult to separate out the impact of individual elements of IEQ on productivity, provision of comfortable and appropriate thermal, luminous and acoustic conditions, adequate ventilation, and access to fresh air with low levels of pollutants, particles, toxins and odours are essential pre-requisites for a productive and healthy working environment. Specific IEQ impacts on productivity are discussed individually in more detail later in this note.

3.2 User Control

As a general rule, occupants want their perceived needs to be met quickly and with as little intervention by themselves as possible. According to Leaman et al. (2007) they normally respond well to IEQ features that enable more choice and control over their environment. Users tend to be more tolerant if they understand how things are supposed to work, and if they have a degree of control over them. Controls should clearly communicate to the user what they are for and how they are supposed to operate. They should provide feedback to the user that they have operated successfully after being used, and, crucially, give some indication that something has happened as a result.

3.3 Furniture and Equipment

Workstations and other furniture and equipment that provide a high level of user control will enhance occupant comfort and performance (Leaman et al., 2007). Furnishings should support good posture, body mechanics, and work techniques for the tasks to be accomplished (e.g. ergonomically designed chairs and keyboards). Users should be able to adjust workstation configurations such as seating, computer equipment placement, light levels, work surface heights and local workspace layout. Use of translucent materials in workstations to provide access to daylight and views can also be beneficial.

3.4 Flexible Workspace Layout

Flexible spaces that provide for multiple spatial configurations, and which allow for rapid and easy change to meet the needs of changing work tasks, across a range of timescales, are essential in facilitating organisational and individual productivity (van der Voordt, 2003). Flexibility features that enhance productivity include:

- maximum flexibility for delivering power, voice and data
- mobile and wireless technologies that support new work styles and work practices. This can enable workers to move effortlessly among spaces as their needs change
- interior design that supports multiple spatial configurations, and a range of different space types and densities to allow workers to move freely from solitary work to group action as required
- informal workspaces in cafeterias and other social or public spaces. If open informal spaces are used, they should be separated from individual quiet work spaces.

Flexible space design can also result in churn savings of 67 to 92 per cent due to the ease of relocation or addition of floor outlets, diffusers, power/data/voice outlets, without additional materials or external contractors (Loftness et al., 2002)

3.5 Positive Psychosocial Features

Workplace productivity can be potentially enhanced by incorporation of positive psychosocial features of workspace and interior design (Heerwagen, 2000). For example, provision of opportunities to engage in social interaction, learning and information sharing can result in improved communication and morale, which can in turn potentially enhance workgroup and organisational productivity. This can be achieved in practice through provision of multiple places to meet and greet, and a centrally located social space nearby well-travelled pathways within the building to encourage use and interaction.

Provision of spaces for individual concentration, and for relaxation and psychological restoration which give occupants an opportunity to temporarily separate themselves from the work environment, as well as opportunities for regular exercise away from the desk, such as stair usage can also have a positive effect on occupant wellbeing. Other positive features which can be incorporated into interior designs include connection to the natural environment, through internal gardens or indoor plants, and the provision of an interesting visual environment with aesthetic integrity (Heerwagen, 2007).

3.6 Access to Daylight and Views of Indoor and Outdoor Nature

A number of studies have show that the negative effects resulting from sustained intense concentration levels can be partially overcome by attentional shifts, especially when the shifts are under the control of the person and

when attention is shifted to a positive component, such as a view of nature (Tennessen and Cimprich, 1995). Positive components also include those which promote psychological and social well-being such as opportunities for social interaction, learning, exercise and privacy (Heerwagen, 2007) Views of nature have also been found to reduce psychological stress and to enhance moods (Kaplan, 1992; Heerwagen and Hase, 2001). In a field experiment of the effects of daylight and views on cognitive performance, Heschong (2006) found that workers with visually interesting views, especially views of natural vegetation, scored better on cognitive tasks than workers with no views or with less interesting views. This case study found a 6 per cent to 7 per cent faster call handling time for employees with seated access to views through larger windows with vegetation content from their cubicles, as compared to employees with no view of the outdoors.

3.7 Aesthetics

Interior spaces should be designed with reference to basic human needs of shelter, comfort and communication, and connections to the patterns of nature. These and other psychosocial features of interior design can have a positive effect on productivity. A visually appealing environment can be provided through a well-balanced and appropriate use of scale, colours, textures, patterns, artwork, and plants. Too much visual uniformity should be avoided, as should too much visual chaos Heerwagen (2007).

4.0 PRODUCTIVITY INHIBITORS IN BUILDINGS

Productivity inhibitors for buildings in which high-level cognitive work is undertaken, are mainly related to characteristics that contribute to, or cause discomforts, distractions, and interruptions. These include:

- noise interruptions and distractions
- visual distractions
- high workstation density
- poor IEQ, particularly thermal comfort levels and air quality.

4.1 Noise Distractions and Interruptions

The use of an open-plan layout to increase communication and flexibility can lead to high level of complaints of distractions resulting from interruptions and people talking (Evans and Johnson, 2000). It should be noted that distractions are less related to the actual noise level than to the degree of individual occupant control over the noise, its content, and its predictability (Kjellberg et al., 1996).

Interruptions are more likely to occur in open-plan offices where people can readily be seen and are thus considered 'available' for interactions. This presents a conflict for designers, because any productivity benefits from increased communication and interaction, and more efficient space-usage in open-plan spaces, must be traded off against the potential for increased noise levels, and associated distractions and interruptions. A common solution is to provide small, enclosed **concentration spaces** for individual concentrated work. However, in an open environment, people may have difficulty moving between their personal workspace and the concentration areas because they often need things that are at their desks, or they want to be able to use their computers, phones and paper documents simultaneously, and this can be difficult to negotiate.

4.2 Visual Distractions

Visual distractions include both people and artefacts. Early research on the landscaped office (a 1950's movement in open plan office space planning) showed that visual distractions associated with continual movement of people in the office created high levels of dissatisfaction. This led to the widespread use of partitioned workstations. Although these have reduced visual distractions, they have not adequately reduced noise distractions. Research also shows that people are similarly distracted by artefacts on their desk, such as document piles, messages and 'to do' lists. The result in most offices is cognitive overload and inability to decide what to do and how to maintain focus (Lahlou, 1999). People frequently switch attention from one thing to another as they are reminded of the need to do something other than what they are currently working on, simply by looking at the note or pile of work left unfinished, or by looking up when someone interrupts them. Visual distractions are more likely to be prominent when workspaces do not have sufficient, readily accessible storage space. However in some contexts, visual distractions may be a result of 'work-system' design factors (such as the breakdown and design of specific tasks and interactions between workers, and their distribution in space) rather than building or interior design.

4.3 Workstation Density

Higher workstation density may lead to lower productivity due to reduced comfort levels, and increased visual and acoustic distractions and interruptions (Fried et al., 2001). Things which assist productivity of office workers like availability of desk space and storage become more scarce in higher density spaces, and cooling, ventilation and lighting systems need to work harder to achieve appropriate comfort levels.

4.4 Poor IEQ

There is a growing body of evidence that poor IEQ can negatively impact on individual and organisational productivity. IEQ effects on productivity are discussed in more detail below.

5.0 INDOOR AIR QUALITY

Indoor air quality (IAQ) refers to the totality of attributes of indoor air that affect a person's health, well-being and comfort. IAQ is characterised by:

- physical factors, such as ambient temperature, humidity and ventilation rates

- Air pollutant factors, such as pollutant levels and exposure times
- Human factors, such as occupant health status, individual sensitivity and personal control.

5.1 Impact on Productivity and Health

Productivity

There is a mounting body of evidence that there is a clear financial motivation for ensuring good IAQ in office buildings. Wyon (2004) reviewed recent research findings and concluded that it was now beyond reasonable doubt that poor IAQ in buildings decreased worker productivity and caused visitors to express dissatisfaction. The size of the effect on most aspects of office work performance was estimated to be as high as 6 to 9 per cent.

Health

Another example from a study of 39 schools in Sweden (Smedje and Norback 2000) showed a 69 per cent reduction in the 2-year incidence of asthma among students in schools that received a new displacement ventilation system with increased fresh air supply rates, compared to students in schools that did not receive a new ventilation system.

Department Head of the Indoor Environment Department at the Lawrence Berkeley National Laboratory, William Fisk estimates that improved heating, ventilation and cooling (HVAC) systems, which could limit the spread of contaminants and pathogens, could potentially reduce respiratory illnesses by 9 to 20 per cent (Fisk, 2002). Based on his estimates for the USA, it can be calculated that in Australia, productivity increases from reduced absenteeism and illness could be as high as $1 billion to $2 billion from reduced respiratory disease; $0.1 billion to $0.5 billion from reduced asthma and allergies; and $1.1 billion to $3.5 billion for a reduction in symptoms associated with sick building syndrome.

5.2 Opportunities for Improving Air Quality

Major contributors to poor IAQ include emissions from new building materials and furniture, emissions from office equipment such as photocopiers and printers, poor HVAC system performance and maintenance, and poor outside air quality (Brown, 1997). Other factors that may contribute to poor IAQ include poor cleaning practices, poor moisture control which can lead to mould (e.g. water leaks or persistent damp surfaces), human occupancy effects (e.g. odours), poorly designed enclosed garages and poor overall building maintenance.

Improved IAQ can be best achieved by reducing or eliminating toxics and odours at their source. Additional strategies include providing adequate ventilation rates, isolating office equipment into well ventilated spaces, controlling moisture to reduce microbial growth, and regularly maintaining the HVAC system (Brown, 1997). Research at the University of Technology, Sydney has also shown that commonly used indoor plants can potentially remove VOCs from indoor air, and that this effect increases with prolonged exposure (Burchett et al., 2005).

6.0 THERMAL ENVIRONMENT

Thermal comfort refers to "a condition of mind which expresses satisfaction with the thermal environment" (ISO, 1994). Thermal comfort therefore describes a person's psychological state of mind about their thermal climate and is usually described simply in terms of whether they are feeling too hot or too cold. Thermal comfort can be difficult to define parametrically because a range of environmental and human factors need to be considered in order to determine what will make people feel comfortable. These factors include air- and operative-temperature, humidity, air velocity, level of personal control, and occupant factors such as clothing type and level of activity.

In practice, a high level of thermal comfort is defined to occur when a high proportion (e.g. 80 per cent or more) of building occupants are predicted to be satisfied with the thermal conditions, based on the above factors. A significant influence on thermal comfort is whether a space is mechanically conditioned or naturally conditioned — these are known to require different physical conditions for thermal comfort, since occupant expectations in the latter are shifted due to different thermal experiences and availability of individual control (i.e. occupant tolerances can be higher in systems with openable windows).

6.1 Impact of Thermal Conditions on Productivity

Many studies have shown a positive relationship between thermal comfort parameters and occupant productivity (Seppanen 2006a, 2006b). In one example, in a controlled field experiment in Japan, Imanarii et. al (1999) identified a significant improvement in measured work efficiency and accuracy of up to 24 per cent improvement among occupants working in an environment with superior thermal comfort conditions. Other studies have shown the link between user control of thermal conditions and productivity. Eight studies, summarised in Kats (2003), show that provision of individual temperature control can increases individual productivity by 0.2 to 3 per cent.

As well as the direct effect on individual health and productivity, poor thermal conditions can potentially increase building maintenance costs due to costs associated with occupant complaints. A study by Federspiel (2001), based on 575 buildings in the USA, showed that nearly one fifth of complaints to facilities managers were related to indoor environment issues, and most of these were related to thermal comfort.

6.2 Opportunities for Improving Thermal Comfort

One of the most important things a designer can do to ensure high levels of thermal comfort, is to establish appropriate thermal comfort criteria, based on appropriate standards and guidelines such as those developed by ASHRAE (2004) and ISO (1994). Where possible, provision of some level of personal control over the thermal environment can help improve occupant satisfaction.

Examples of personal control include operable windows, personal ventilation controls or a personal fan or heater.

Once thermal comfort criteria have been established, these need to be monitored and maintained over time by building managers. Given that thermal comfort is largely defined by occupant satisfaction levels, monitoring requires the incorporation of occupant feedback, to maintain comfort levels under different conditions and contexts. Occupant feedback should be actively sought by building managers, listened to, and acted on quickly where necessary.

7.0 ACOUSTIC ENVIRONMENT

The acoustic environment quality refers to the totality of the acoustic characteristics of a building interior that impact on occupant aural perceptions. Occupant perceptions of the acoustic environment quality have important implications for comfort and productivity and can be affected by:

- levels of background noise
- reverberation times and sound absorption
- information content of the noise
- noise transmission between spaces
- speech intelligibility
- personal control and intermittency of the noise.

Different types of office spaces, such as workstation clusters, social spaces, executive suites, conference rooms and boardrooms, will have specific acoustic requirements depending on the function of the space.

7.1 Impact of Acoustic Environment on Productivity

Of all the aspects of IEQ, noise levels, are the most frequent cause of the greatest occupant dissatisfaction in office environments (Jensen et al., 2005). However, in some contexts, this may be a result of work-system factors rather than the building or interior design. Work-system factors include for example the breakdown and design of specific work tasks, design of interactions between workers, and the distribution of tasks and interactions in space Contributors to dissatisfaction with acoustics and noise can be caused by interruptions, equipment noise and lack of privacy or control over noise. The major sources of acoustic dissatisfaction in office buildings include:

- speech interruptions, such as people talking over the phone, in adjacent areas and corridors
- equipment noise
- excessive background noise from HVAC and lighting systems
- lack of conversational privacy
- lack of personal control over noise levels
- space being acoustically too 'lively' or too 'dead'.

The levels of background noise and speech privacy, and separation between particular types of spaces have important implications for the work environment and productivity of building occupants. As outlined above, many problems associated with office spaces relate to interruptions by other employees. Distractions due to the sound of speech have been found to be significantly problematic, especially in open-plan offices. This is because speech is more distracting than unintelligible speech or sounds with no information content. Conversely, office spaces with very low background noise can have poor levels of speech privacy which can also hinder communication. It is a challenge for designers to find the correct compromise between privacy and intelligibility for specific contexts. A detailed review of acoustic satisfaction in open-plan offices is given in Navai and Veitch (2003).

7.2 Opportunities for Improving Acoustic Environment

In essence, noise can be controlled by:

- eliminating the source
- isolating the source
- masking the unwanted sound.

Following these basic principles, strategies for creating a high-performance acoustic environment include:

- identifying noise sources and establishing appropriate criteria for background noise, transmission of noise between spaces and speech privacy levels
- separating noise-sensitive and noise-producing areas, including provision of opportunities for privacy and concentration, when needed, in open-plan offices
- considering the impacts of building services on ambient conditions. Steps should be taken to minimise background noise from the building's HVAC system and other equipment, where necessary, by using passive or active methods
- selecting appropriate surface finishes to control sound reverberation times
- limiting transmission of unwanted noise from outside the workplace
- using sound masking systems to maintain appropriate balance between speech privacy and intelligibility.

8.0 LUMINOUS AND VISUAL ENVIRONMENT

The luminous and visual environment quality refers to the totality of the luminous and visual characteristics of a building that impact on occupants' visual perceptions. Occupant perceptions of luminous and visual environment quality can be affected by the following:

- luminance levels (ambient and task) for different tasks, and their uniformity
- glare levels, reflections in computer screens
- levels of personal control through task lighting, shading or dimmers
- access to daylight and views
- lighting characteristics, such as colour temperature and ballast flicker
- visual appeal and colour scheme of interior design.

8.1 Impact of Luminous and Visual Environment on Productivity

Luminous and visual environment quality can have a significant impact on occupants' abilities to perform tasks, especially if they are visually intensive. Major sources of dissatisfaction with the visual environment include limited access to daylight, inappropriate light levels, excessive glare and lack of control over the environment.

Various studies have shown a link between lighting quality and productivity. Kats (2003) summarised a series of case studies, which indicated productivity gains ranging from 0.7 to 23 per cent were achieved in buildings with higher quality lighting fixtures and/or access to daylight. Cakir and Cakir (1998) also identified a health benefit from the use of more extensive task lighting. Their study showed a 19 per cent reduction in headaches for workers with separate task and ambient lighting, as compared to workers with ceiling-only combined task and ambient lighting.

8.2 Opportunities for Improved Performance

In any given office environment, occupants should be able to see easily, comfortably and accurately. The illumination level required to achieve these results will vary, depending on the given activity taking place and the characteristics of the occupant. The illumination level required for most spaces and environments is a function of the type of activity or task being undertaken, the importance and difficulty of the visual aspects of the task, and the age and visual capabilities of the occupant.

Practical strategies for creating a high-performance luminous and visual environment are based on maximising occupant visual comfort, and include:

- providing appropriate and adjustable task lighting, and where possible, adjustment of ceiling lights
- integration of natural and electric lighting strategies, including suitable arrangement of fittings with respect to building and workspace layout
- using day-lighting for ambient lighting wherever feasible
- use of high-performance ballasts, lamps, fixtures and controls
- reducing direct glare from both natural and man-made sources in the field of view. Shading can be combined with light redirection to provide for an effective day-lighting strategy while reducing glare.
- providing light on vertical surfaces/walls and light-shelves to increase the perceived brightness of the space
- providing internal and external views of nature and visually appealing aesthetics
- avoiding too much visual uniformity, as well as too much visual chaos
- cleaning windows and lights regularly to maximise daylight and illumination levels.

9.0 CONCLUSION

Good IEQ can have a positive impact on occupant health, wellbeing and productivity at individual and organisational levels. Conversely, poor IEQ can have a significant negative impact. Provision of good IEQ is becoming increasingly important for other reasons as well, such as minimising compliance costs with any potential future regulations related to IEQ, attribution of 'points' towards higher sustainability ratings, organisational image and worker retention and attraction.

Some specific strategies to assist in designing for good IEQ have been outlined herein. It should be noted however, that good IEQ is a necessary, but not sufficient pre-requisite for enhanced productivity, since other factors, specific to individual contexts, and not directly related to IEQ, can also have a significant impact. In some contexts, factors outside of the designers control may dominate productivity considerations. Although the information outlined herein is targeted specifically for office buildings, many of the principles can be applied to other building types as well.

ACKNOWLEDGEMENTS

Some of the material summarised in this note has been developed for the *Your Building* online commercial building sustainability resource portal, an initiative of the Cooperative Research Centre for Construction Innovation (www.yourbuilding.org), and a chapter in a book (Paevere, 2008). The Author would like to acknowledge the valuable contributions of Stephen Brown, Judith Heerwagen, Adrian Leaman and Mark Luther.

REFERENCES

ASHRAE 2004, *ANSI/ASHRAE Standard 55-2004: Thermal Environmental Conditions for Human Occupancy*, Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.

Burchett, M, Wood, R, Alquezar, R, Orwell, R, Tarran, J and Torpy, F, 2005, *How and why potted-plants really do clean indoor air*, Technical report for the Flower Council of Holland and Horticulture Australia, Sydney: Plants and Environmental Quality Group, Faculty of Science, UTS.

Brown, SK, 1997, *National state of the environment report – indoor air quality*, SoE Technical Report Series, Canberra: Department of Environment, Sports & Territories.

Browning, W and Romm, J, 1994, *Greening the building and the bottom line: increasing productivity through energy-efficient design*, Rocky Mountain Institute, Snowmass, Colorado, USA.

Cakir, AE and Cakir, G, 1998, Light and Health: Influences of Lighting on Health and Well-being of Office and Computer Workers, Ergonomic, Berlin.

Evans, GW, and Johnson, D, 2000, Stress and open-office noise, *Journal of Applied Psychology*, 855, 779–783.

Federspiel C, 2001, Estimating the frequency and cost of responding to building complaints, in Spengler, J, Sammet J, and McCarthy, J, (eds), *Indoor air quality handbook*, McGraw Hill.

Fisk, WJ, 2002, How IEQ affects health, productivity, *ASHRAE Journal*, 445, 56–60.

Fried, Y, Slowik, LH, Ben-David, HA and Tiegs, RB, 2001, Exploring the Relationship between Workspace Density and Employee Attitudinal Reaction: An Integrative Model, *Journal of Occupational and Organizational Psychology* 743:359-372.

Heerwagen, J, 2007, *Psychosocial Value of Spaces*, JH Heerwagen & Associates, Inc., National Building Design Guide, National Institute of Building Sciences.

Heerwagen, J 2000, Green buildings, organizational success and occupant productivity, *Building Research and Information*, 28 5, 353-367.

Heerwagen, J and Hase, B, 2001, Building biophilia: connecting people to nature in building design, *Environmental Design and Construction*, Apr/May: 30–34.

Heschong, L, 2006, Windows and office worker performance: the SMUD call center and desktop studies, in Clements-Croome, D, ed, *Creating the productive workplace*, 2nd edition, London and New York: Taylor and Francis, pp. 277–309.

Imanari, T, Omori, T, and Bogaki, K, 1999, Thermal comfort and energy consumption of the radiant ceiling panel system, Comparison with the conventional all-air system. *Energy and Buildings* 30:167-175

ISO 1994, *ISO 7730: Moderate Thermal Environments – Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort*, Switzerland.

Jensen, K, Arens, E and Zagreus, L, 2005, *Acoustic quality in office workstations, as assessed by occupant surveys*, Proceedings of Indoor Air 2005, Beijing, September 4–9.

Kaplan, R, 1992, Urban forestry and the workplace, in Gobster, PH ed , Managing urban and high-use recreation settings, USDA Forest Service, *General Technical Report NC-163*. Chicago: North Central Forest Experiment Station.

Kats, G, 2003, *The costs and benefits of green buildings*, A report to California's Sustainable Building Task Force.

Kjellberg, A, Landstrom, U, Tesarz, M, Soderberg, L and Akerlund, E, 1996, The effects of nonphysical noise characteristics, ongoing task and noise sensitivity on annoyance and distraction due to noise at work, *Journal of Environmental Psychology*, 16, 123–136.

Klepeis NE, Nelson, WC, Ott, WR et al., 2001, The National Human Activity Pattern Survey NHAPS: a resource for assessing exposure to environmental pollutants, *Exposure Analysis and Environmental Epidemiology 2001*, 11, 231–252.

Lahlou, S, 1999, Observing cognitive work in offices, in Streitz, NA, Siegel, J, Hartkopf, V and Konomi, S, eds, *Cooperative buildings: integrating information, organizations and architecture*, 2nd International Workshop, CoBuild 99, Pittsburgh, 1999.

Leaman, A, Thomas, L and Vandenberg, M, 2007, Green Buildings: What Australian Users are Saying, *EcoLibrium*, November 2007, AIRAH.

Leaman, A, and Bordass, B, 2006, Productivity in buildings: The "killer" variables, in Clements-Croome, D. ed, *Creating the productive workplace*, 2nd edition. London and New York: Taylor and Francis, pp. 277–309.

Loftness, V, Brahme, R, Mondazzi, M, Vineyard, E and MacDonald, M, 2002, *Energy savings potential of flexible and adaptive HVAC distribution systems for office buildings*, Arlington: Air-Conditioning and Refrigeration Technology Institute ARTI

Navai, M and Veitch, JA, 2003, *Acoustic satisfaction in open-plan offices: review and recommendations, Report IRC-RR-151* to National Research Council of Canada.

Paevere, P, 2008, Indoor Environment Quality and Occupant Productivity in Office Buildings, in *Technology, Design and Process Innovation in the built Environment*, Taylor and Francis Books Ltd.

Paevere, P, and Brown, S, 2008, *Indoor Environment Quality and Occupant Productivity in the CH2 Building: Post-Occupancy Summary. Report No. USP2007/23*. CSIRO Sustainable Ecosystems.

Purdey, B, 2005, GEN 67: Green buildings and productivity, *BEDP Environment Design Guide*, Australian Institute of Architects.

Seppänen, O, Fisk, WJ and Lei, QH, 2006a, Ventilation and Performance in Office Work. *Indoor Air*, Vol 16 1, 28–36. International Society of Indoor Air Quality and Climate ISIAQ, Lyngby, Denmark.

Seppänen, O, Fisk, W and Lei, QH, 2006b, *Effect of Temperature on Task Performance in Office Environment. Proceedings of Cold Climate*, HVAC Conference, Moscow, Russia.

Smedje, G and Norback, D, 2000, *New ventilation systems at select schools in Sweden—Effects on Asthma and Exposure,* Archives of Environmental Health, 351, pp. 18-25.

Tennessen, CM and Cimprich, B, 1995, Views to nature: Effects on attention. *Journal of Environmental Psychology*,15:77-85

van der Voordt, DJM, 2003, *Costs and Benefits of Innovative Workplace Design*, Centre for People and Buildings, Delft.

Wyon, DP, 2004, The effect of indoor air quality on productivity and performance, *Indoor Air*, 147, 92–101.

BIOGRAPHY

Dr Phillip Paevere, BE Hons, PhD is a Senior Research Scientist with CSIRO Sustainable Ecosystems: Urban Systems Program. He currently leads a portfolio of research projects which develop advanced concepts, technologies and products to increase the sustainability and functionality of the world's built urban environments. Dr Paevere has published more than 70 building-related research works and has been awarded numerous scholarships and international research awards. He is a member of the editorial board for the *Australian Journal of Construction Economics and Building*, and the *Open Construction and Building Technology Journal*. He recently led an extensive research project on IEQ and productivity in the CH2 building in Melbourne.

APPENDIX

CASE STUDIES

Building Description

Council House 2 (CH2) is a 10-storey office building in Melbourne which houses around 500 City of Melbourne staff, and some ground-floor retail space. The office levels of CH2 were occupied in October 2006. The building was conceived, designed and built with a substantial focus on setting a new standard for ecologically sustainable office buildings (Paevere and Brown, 2008). It has a raft of sustainable technologies and design philosophies incorporated throughout the entire building, services and fit-out. A key element of the business case for CH2 was that provision of high levels of IEQ, along with other design features, would result in significant benefits to City of Melbourne through improved health, well-being and productivity of staff in the building. Many IEQ-related features of CH2 incorporate principles outlined in this note, and include:

- 100 per cent fresh air ventilation
- radiant cooling provided by the thermal mass of concrete ceiling panels, and also through chilled panels
- lighting provided through a mix of high-efficiency recessed luminaries in the ceiling, suspended strip lighting, daylight penetration, and extensive task lighting.
- low toxicity materials used for all furnishings and finishes
- extensive use of indoor plants.

The interior design was also intended to produce productivity benefits through increased communication and collaboration between staff. The fit-out is based on a modern open-plan philosophy, with no enclosed offices and low adjustable partitions between workstations. Staircases have been located to encourage staff to walk between nearby floors. There are relatively unobstructed lines of sight throughout each floor, with the only enclosed spaces being the formal meeting rooms. Informal meeting and social spaces are provided throughout the building. Occupants also have access to external balconies, a winter garden (glazed balcony enclosures adjacent the external stair), a summer terrace and a rooftop garden.

Productivity of CH2 Occupants

Perceived productivity ratings show that CH2 achieved a significant productivity improvement when compared to the previous accommodation located next door, despite some problems with lighting and increased noise levels due to the open-plan layout. Three quarters of CH2 occupants rated the building as having a positive or neutral effect on productivity, compared with just 39 per cent previously. CH2 was rated in the top 20 per cent of Australian buildings for perceived productivity when compared against a benchmark dataset (Building Use Studies benchmarks). This can be expressed as a 10 per cent perceived productivity enhancement compared to previous accommodation. Contextual indicators showed little change for non-building related influences on productivity (Paevere and Brown, 2008).

Based on the results of occupant questionnaires and a program of physical measurements, it was shown that the significant improvement in perceived productivity achieved could be best correlated to variables relating to the 'building overall' such as the building image, quality of design, perceived healthiness, and overall comfort. It was shown that other factors, such as experiences in previous accommodation may also influence the results. In terms of IEQ impacts on productivity, it was concluded that significantly improved thermal comfort and air quality are likely to have had an enhancing effect on productivity perceptions while noise from interruptions and perhaps some aspects of the lighting may have been perceived by occupants as a productivity hindrance. Full details of this case study and the productivity analysis are given in Paevere and Brown (2008).

The views expressed in this Note are the views of the author(s) only and not necessarily those of the Australian Council of Built Environment Design Professions Ltd (BEDP), The Royal Australian Institute of Architects (the Institute) or any other person or entity.

This Note is published by the Institute for BEDP and provides information regarding the subject matter covered only, without the assumption of a duty of care by BEDP, the Institute or any other person or entity.

This Note is not intended to be, nor should be, relied upon as a substitute for specific professional advice.

Copyright in this Note is owned by The Royal Australian Institute of Architects.