

Sustainable Intelligent Buildings for Better Health, Comfort and Well-Being

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Contents

Abstract	3
Introduction	3
Energy Picture	4
Do Green Buildings Have a Better Indoor Environment?	7
Do Green Buildings Affect Human Performance?	7
Do Buildings Affect People's Health?	8
Other Survey Evidence from Users	10
Environmental Factors	12
Beyond Environmental Comfort	16
The Nature of Productivity	20
Effects of Thermal Environment and Productivity	23
Measurement of Productivity	23
Sick Building Syndrome	25
Well-being	25
Well-being and Productivity (Clements-Croome, 2006)	29
Conclusions	31
Recommendations for Planning Design and Management of Intelligent Buildings	32
Now and The Future	34
Acknowledgements	36
References	36
Further References	47

Sustainable Intelligent Buildings for Better Health, Comfort and Well-Being

Abstract

The Report examines how the built environment affects our well-being and this in turn influences our work effectiveness in the workplace. Poor environments contribute to absenteeism and also to people not working as well as they might which is referred to as presenteeism. This is an enormous cost to the UK whereas good design could save in the order of £135 bn per year by increases in productivity and reduced medical costs (Wheeler and Almeida 2006). Black (2008) records that the economic costs in the UK of sickness absence and presenteeism are over £100 bn per year. The economic loss due to poor design is not only in low productivity but also in wastage of energy because designing for sustainability results in environments that are not only better in human terms but tend to be leaner in terms of energy consumption. High quality environmental design is an investment as occupants are healthier, staff retention rates are higher, productivity is higher and sustainability ideals such as lower energy consumption are more likely to have been met. Fresh air at appropriate temperatures, daylight, views outside, colour, acceptable sound levels, spatial arrangements, ergonomics and greenery are all factors which contribute significantly to our mood and well-being in the workplace but also impact energy needs. Intelligent buildings need to bring together all these aspects into a holistic whole.. Recommendations will be made for the design of healthy sustainable buildings.

Introduction

We live through our senses. What we see, hear, touch, taste and smell affect our human system physiologically and psychologically. We need fresh air to live to nourish our blood with oxygen and then the organs of our body including our thinking brain. The air has to be warm or cool enough as well as being clean. We also need light to see. The aural climate has to be acceptable. Buildings are designed to naturally attune the internal conditions to those needed for living and working in but often they need extra help by installing systems of

heating, cooling, ventilation and lighting within them to fine tune conditions of temperature, humidity, indoor air quality, lighting and sound. These systems consume energy not only in operation but also during the manufacture and production of them called the embodied energy arising from making, assembling, transporting and installing them. Likewise the materials used for the building structure have embodied energy.

The world now recognises the need to minimise resource consumption like fossil fuels so the need is to design low energy buildings but can we do this without sacrificing the human needs for sensitive built environments? Clements-Croome (2013a) in his Dreosti lecture showed that by using low tech passive design and adopting some of the strategies used in Nature it is possible to even have buildings which generate energy but at the very least develop low carbon architecture which is sensitive to human needs. According to Professor Olli Seppanen in his Editorial for the June 2014 Issue of The REHVA European HVAC Journal.

Good indoor environment should not be sacrificed for low energy use

Together good environments and effective- efficient energy strategies can increase the asset value of building stock (Sivunen et al 2014). The link between health, well-being and sustainability as demonstrated through employing green design measures will become evident in the discussion which follows.

Energy Picture

Energy efficiency is unarguably an important societal, even planetary goal. However seeking lighting efficiency at the expense of individuals or their organisations well-being is unlikely to succeed (Veitch et al., 2010)

Currently in the EU energy consumption in buildings accounts for around 40 per cent of total energy consumption and generate around 37 per cent of the overall carbon emissions. About 35% of this consumption is providing heating, cooling and ventilation. If we add in the energy for lighting one can see that the energy consumption used for meeting peoples' comfort or well-being needs is highly significant. It is important therefore to ensure we properly understand the human requirements and just do not 'guess' them and add in very large margins for contingencies which are wasteful.

It is estimated that by 2050 three quarters of actual buildings will be still in place while one quarter will represent new buildings constructed from today onwards. Therefore, energy consumption in buildings has become an essential part of all strategic lines of the EU's energy policy in terms of energy security, competitiveness together with environmental and climate respectfulness.

It is important to reach a decrease of 88 per cent to 91 per cent of 1990 CO₂ levels by 2050 as identified by the EU roadmap for moving to a competitive low carbon economy. And finally, to radically reduce the use of resources as buildings are identified by the roadmap for a resource efficient Europe as being one of three key sectors – together with food and transport – responsible for 70-80 per cent of all environmental impacts.

In order to help the construction industry reach carbon reductions of 20% by 2020 and achieve energy neutral buildings and districts by 2050 the European Construction

Technology Platform has set up the Energy Efficient Building European Initiative (E2B EI), steered by the Energy Efficient Buildings Association (E2BA) founded in November 2008. In EU energy terms this is a reduction from about 1678 Mtoe at present levels to 1474 Mtoe by 2020 over the 28 member states.

Passive design can reduce the energy needs using natural cooling and heating systems so the link between the architecture, the location and the mechanical systems is vitally important.. Does economical use of energy mean conditions for good well-being have to be sacrificed? With careful design a balance can be struck which ensures that buildings are healthy and enhance well-being. Research by Pelenur and Cruickshank (2013) highlighted a disconnect between well-being and domestic energy consumption and they conclude further research is required in this area otherwise there is a risk that national energy policies may negatively affect peoples' happiness and well-being. There is universal agreement that an integrated systemic approach to design and management is essential to attain truly sustainable architecture that is economical in the use of resources but also increases the quality of life.

We have to understand not only how buildings and systems behave in various environments but the building occupants too as they can greatly influence the patterns of energy use (Guerra-Santin and Itard 2010; Zeiler et al., 2014). In the work of Zeiler et al (2014) the human influence was 3—5 times higher than variations in the building parameters.

The Forging Behaviour Model (Fogg 2009) defines human behaviour in terms of motivation, ability and the trigger defined as the signal or prompt to undertake a certain action.

Behaviour = Motivation x Ability x Trigger (MAT)

Fig 1 below shows when the motivation and ability act together at a certain point this prompts or triggers a particular behavioural response (Fogg 2009). Motivation arises from the job interest; the organisations' ethos and culture; the social climate but the built environment also has a role to play and this has often been not realised or ignored.

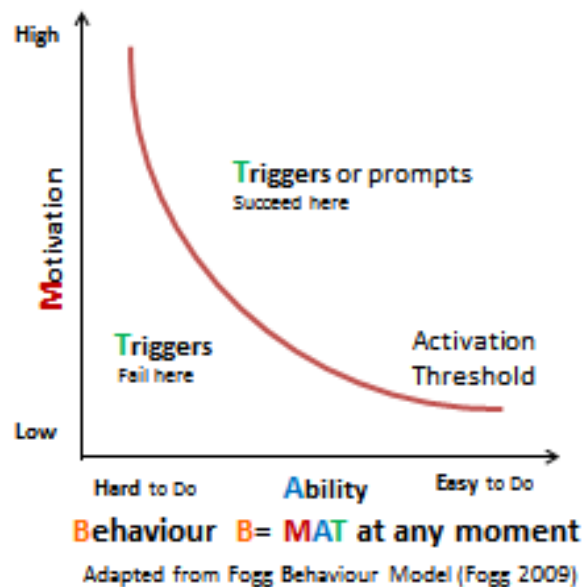


Fig 1 Fogg Behaviour Model (2009)

Cost can be the trigger that motivates people to change their behaviour if they have the ability to make the changes. Smart meters can prompt people who can use them to see how their actions influence energy consumption and lead them to modify their use of energy consuming products which are part of everyday life. The energy performance gap is due to several factors for example, incorrect initial specifications, incorrect installation of equipment; lack of commissioning; incorrect operation after construction; poor facilities management; and manufacturers over estimating the performance on product labelling .However the effects of occupant behaviour on energy consumption are very significant and this is detailed in a Special Issue of the journal Architectural Engineering and Design Management in 2014 Volume 10 Numbers 1 and 2 published by Taylor and Francis.

Low energy consumption can be achieved but this requires consideration throughout the planning, design, commissioning and operation stages. Post-occupancy evaluation is essential to capture the feedback which can continually prompt actions for improvement in performance. It is important to use a user-centric approach so that the occupant is part of the process in the ways suggested above. Spataru and Gauthier (2014) show ways of monitoring people to help reduce energy consumption. The interfaces between the occupants and the various controls need to be clear and easy to use. Zeiler et al.,(2014) reports research that

shows that displaying real- time energy use to occupants using smart energy meters can reduce consumption by 5—15%.

As regulations tighten on energy the role of the occupant becomes more and more important. In the UK each deg C either downwards for heating in Winter or upwards for cooling in Summer is equivalent to an energy saving of about 8%. With climate change bringing milder Winters and warmer Summers in cooler temperate climates the main complaints about the thermal conditions are becoming more significant in Summer than Winter. We need to appreciate not only the factors which directly influence energy or well-being but also the indirect linkages too.

Do Green Buildings Have a Better Indoor Environment?

Newsham et al (2013) carried out a detailed study reviewing old evidence and offering new insights based on a post-occupancy evaluation of 12 green and 12 conventional office buildings. Overall they concluded green offices tend to have better indoor environmental performance compared with conventional ones in terms of satisfaction with the environment, views, aesthetic experience, well-being including mood and physiological symptoms. The work also showed that the sustainability rating systems –in this case LEED—need further development regarding the credits allowed for some of the environmental factors.

This work echoes the findings of Miller et al (2009) and Kok et al (2012).

Reed et al (2009) makes a comparison of rating tools which are used worldwide to evaluate how well a building stands in sustainability terms. In the UK the BREEAM rating tool for example health and well-being are one of nine categories and has a 15% credit (BSRIA 2012). There are various criticisms made about rating tools such as: they are too complicated; too inflexible and the credit allowances can be questioned but by designers using them clients can realise that they do lead to savings in energy and waste; reduced operation costs and resulting in higher rental value and improved occupant satisfaction (BSRIA 2012). Other measures of building quality include the Building Quality Assessment- DQA (Williams 2006) the design quality indicator-DQI (Construction Industry Council, 2002) and the many rating tools available such as BREEAM, LEED, Green Star ; CASBEE; NABERS; SuBET (Alwaer and Clements-Croome 2010) and others.

Do Green Buildings Affect Human Performance?

Architecture is more than the art of constructing individual buildings. It is also the creation of environment. Buildings do not exist in isolation. They not only impose their character on their surroundings but also have an incalculable effect on the lives of human beings who inhabit them.

Conti (1978)

Miller et al. (2009) surveyed over 500 tenants who had moved into LEED (Leadership in Energy and Environmental Design) and Energy Star rated buildings, and proved their hypothesis that healthy buildings reduce the number of sick days and make it easier to recruit and retain staff. In addition over half of the employers found their employees to be more

productive (Kok et al 2012). Other evidence supporting this is showing that sustainable buildings decrease business and energy costs, and increases the value of the built asset as the increasing societal awareness of green buildings deepens and leads to an increasing client demand for sustainable buildings (Clements-Croome, 2004a,b; Newell, 2009; Thompson and Jonas, 2008; Kok et al 2012; McGraw Hill Construction 2013 and 2014; Loftness and Haase, 2013; Sivunen et al 2014). Legislation is forcing the pace.

The question now is ‘Can one afford not to be sustainable?’ According to Bernstein and Russo (2010) US environmentally labelled buildings rent for 2–3% more and have higher staff retention rates and decreased operating costs, and in 2008 the value of these buildings increased by 10%. Newell (2009) quoted evidence showing that LEED-rated buildings cost 6% more to build, have staff retention rates over 4% higher, command 2–6% higher rents and save 10–50% in energy consumption. Integrated design and management processes may reduce this extra build cost of about 6% to the point where there is no extra cost (Rehm and Ade 2013).

There seems to be a virtuous circle linking health, sustainability and environmental quality. Better building performance is likely to lead to better well-being and as a consequence better performance. Of course, other factors are important, such as job satisfaction, the social ambience in the workplace and personal issues. Here, ‘health’ relates to both mind and body. Our surroundings can influence our moods, our concentration, and enhance or detract from our basic motivation to work. Some people are more sensitive to their surroundings than others, but we should aim to satisfy the most sensitive people rather than design for average preferences, which neglect individual differences. Voordt (2003) believes that employees who have interesting and beautiful environments to work in tend to be more productive. Productivity depends on the organisations’ management processes and culture; the social settings; personal issues as well as the built environment and so is a multi-layered concept (Clements-Croome 2006). Nevertheless there is much research and anecdotal evidence which has established the built environment has an important role to play.

Do Buildings Affect People’s Health?

Over the past 20 years, it has been empirically assessed that most building environments have a direct effect on the occupants’ physical and psychological health, well-being and performance; however, it is only through more recent studies that a clearer understanding of the occupied environment has been discovered. Bako’-Biro’ *et al.* (2008, 2012) have shown that primary school children’s concentration is affected by CO₂ levels between 1000–5000 ppm, and hence the design for ‘effective’ fresh-air ventilation is vital. Effective means the fresh air reaches the breathing zone and vital because there is an effect on learning performance. Satish *et al.* (2011, 2012) describe research evidence showing that CO₂ affects decision-making even at levels as low as 600 ppm, which is below the normally accepted level of 1000 ppm. This raises the question as to the validity of the codes and standards we have used for years without question concerning noise, light and temperature. In the UK, the Building Schools Exhibition and Conference (CIBSE, 1999) asked head teachers if they felt modern buildings affect learning. Around 78% said they felt there was a clear link between the quality of school design and levels of pupil attainment. Williams (2006) reported a similar conclusion for 12 primary schools, which he assessed using the building quality assessment

(BQA) method and compared the BQA scores with examination results. There was a clear correlation between building quality and students' performance.

The report *The Drive Toward Healthier Buildings: The Market Drivers and Impact of Building Design on Occupant Health, Well-Being and Productivity*, published in the US by McGraw Hill Construction (2014) in cooperation with the American Institute of Architects states that 18% of home owners say doctors are their primary source of information about healthy home products and decisions – after friends, family and peers. Yet only 53% of paediatricians, 32% of GPs and 40% of psychiatrists believe buildings affect patient health. Similarly many in UK Local Authorities often those who control the finances do not believe school buildings have any effect on children's learning (Abdul-Samed and Macmillan 2005). The McGraw Hill Construction report is based on the findings of five separate market research studies which included surveys of non-residential architects and contractors and owners; residential builders and architects; US homeowners; human resource executives at US firms; and a survey of medical professionals.

In contrast to physicians the report states that 95% of homeowners believe that hospital buildings affect patient/staff health and productivity. Likewise 90% believe school buildings affect student health and productivity. In addition, 63% of the general public is aware of a link between products and practices they use at home and their health, with 50% indicating an impact on allergies and 32% pointing to an impact in asthma and respiratory illnesses. Human resource executives also recognise the link between buildings and health. In particular 66% believe that spaces that encourage social interaction are important when making leasing decisions.

Similar results were found in schools. The health of pupils and staff improved and as a result learning was enhanced when old or new schools had green credentials in their design (McGraw Hill Construction 2013). This was in addition to the energy reduction benefits.

McGraw Hill Construction (2014) states that construction industry professionals are placing increasing attention to health in design and construction plans. According to the study, firms focusing on green buildings are more attuned to health issues, and all firms questioned report an increase in addressing occupant health in design and construction. After many years of concentrating on minimising resource demands for energy and water there has been a shift to balance this need with human values.

This report shows the results for a survey of non-residential property owners beliefs and found significant benefits from healthy buildings:

- 47% a reduction in the cost of healthcare ranging from 1% to 5%.
- 66% improved employee satisfaction
- 56% lower absenteeism
- 21% higher employee productivity.

There is a need to: create greater public awareness of the health impacts of buildings; increase the focus on better tools and methodologies to collect data and measure healthy impacts; and encourage building codes to place increased emphasis on healthier building practices. If we only concentrate on energy we are in danger of neglecting the real purpose of architecture which is to provide for people's well-being. A balance between these requirements is necessary.

Other Survey Evidence from Users

Employers are recognising that good health is a total business issue, and a lack of it affects work performance - Towlers Watson (2014)

The main conclusions from the Gensler 2013 Workplace Survey of some 2000 knowledge office workers in US were:

-
- US workers struggle to work effectively
 - Need to balance focus and collaborative working to afford higher job satisfaction and performance
 - Personal choice drives performance and innovation and improves the workplace experience
 - Think holistically about the needs for focus, collaboration, learning and social ambience leading to variety of spaces offering anywhere working policy
 - Drivers of focus are functionality, satisfactory noise levels and design look and feel.
 - Drivers of balance are meeting space, circulation and support space, in-office amenities
 - Drivers of choice are variety of spaces, tools, policy to let employees match their space to their needs.
 - Less space per person is a false economy as work effectiveness decreases.
 - Offices provide a 'home' for 'work families'
 - Building can give a sense of pride to employee
-

Gensler's use their Workplace Performance Index SM (WPI) derived from a web base measurement and analysis pre and post occupancy evaluation tool for work environments to help clients understand specifically what comprises space effectiveness so that design solutions can be tailored accordingly.

Peer reviewed research and case studies used in the World Green Building Council (WGBC) 2013 Report *The Business Case for Green Building* show that:

- Green buildings do not necessarily cost more and appeal to tenants because they command higher rents and sale prices.
- Operating costs lower because of reduced energy and water use plus reduced maintenance
- Better environments affect employees and lead to higher staff retention rates
- Workplace illnesses and hence absenteeism are reduced ---whilst well-being is higher than in conventionally designed offices where high quality environments have not always been a priority.

McGraw Hill Construction (2014) Report *The Drive to Toward Healthier Buildings* state Metric and Benefits for Healthier Buildings in ranked order as judged by owners and managing directors of companies are:

- Greater Self- assessed Productivity

- Lower absenteeism
- Reduced healthcare costs
- Improved Employee Satisfaction
- Improved Employee Engagement
- Improved Ability to Attract New Talent

Self-assessed Productivity and Satisfaction can be measured using subjective scales like the BUS surveys by Leaman and Bordass (1999; 2006) have done but the other four factors can show quantitative data. The Leesman Index is another satisfaction survey approach (info@leesmanindex.com). In time we will advance the metrics and measures for example by the increased use of wearables (embedded wireless sensors in clothing or accessories) and more comprehensive feedback will lead to enhanced POE (Spaturu and Gautier 2014),.

Sivunen et al (2014) state that building owners and tenants can financially benefit from sustainability and improved indoor environmental quality via:

- Reduced life-cycle costs
- Extended building and equipment life span
- Longer tenant occupancy and lease renewals
- Reduced churn costs
- Reduced insurance costs
- Reduced liability risks
- Brand value

The work of Lützkendorf and Lorenz (2011) as well as the previous work referred to above confirms these conclusions.

McGraw–Hill (2014) states that there is a lot of valid research that supports the hypothesis that the built environment affects human health and some of this has been referred to already.. Environment can ease or increase stress. Physiological or psychological stress can suppress the immune system making people more susceptible to infection.

Too often buildings are seen as costly static containers rather than as investments which, if they are healthy and sustainable, can add value. Boyden (1971) distinguished between needs for *survival* and those for *well-being*. Human beings have physiological, psychological and social needs. Heerwagen (1998) pinpointed the well-being needs relevant to building design as:

- social milieu
- freedom for solitary or group working
- opportunities to develop self-expression
- an interesting visual scene
- acceptable acoustic conditions
- contrast and random changes for the senses to react to
- opportunities to exercise or switch over from work to other stimulating activities
- the need for clean fresh air.

Stokols (1992) states that physical, emotional and social conditions together are a requisite for good health.

In practice, investors, developers and clients often agree that sustainable healthy buildings are desirable but want quantified economic evidence to persuade them to finance such projects. Social awareness is changing about the need for sustainable green buildings. The US Green Building Council published a report in 2003 entitled *Making the Business Case for High Performance Green Buildings* and some of the conclusions included:

- higher capital costs are recoverable in a comparatively short time
- integrated design lowers operating costs
- better buildings equate to better employee productivity
- new appropriate technologies may enhance health and well-being
- healthier buildings can reduce liability
- tenants' costs can be significantly reduced
- property value will increase
- communities will notice your efforts
- using best practices yields more predictable results, but remember that occupancy behaviour affects the performance
- respect the landscape and open space near the building.

Macmillan (2006) discusses the types of value created in the built environment which contribute to the assets of the building owners; the corporate identity ; the occupants; the community; the ecology; the culture of the place buildings are and to the history of our civilisation.

Note perceptions are not always the reality hence it is vital we have coordinated data collection systems using modern developments such as wireless sensor networks connecting people to their environment and building to obtain measured data in real time. Perceptions can be coloured by emotions and reactions to a multitude of stimuli can be dominated by one perceived negative or positive factor which skews the judgement.

Environmental factors

How people feel about their physical surroundings, can impact on not just mental health and wellbeing, but also physical disease

Scottish Government, 2006

In researching the impacts of the environment on people it is common to read that environmental factors can act as stressors. Odours, sound, air quality, temperature and light tend to affect humans through four different mechanisms: physiological, affective, stressful and psychosomatic.

Stressors can cause increased heart rate, vomiting, shallow breathing and muscle tension. They can affect brain rhythms and alter the alpha, beta and theta patterns, which are correlated with mood and affect. Affective states affect judgement, productivity, interpersonal relations, self-image, morale and aggression. So one can see the chain of possible physiological and psychological reactions that may occur when exposed to the environment. There are clues here also as to how physiological measures may aid our understanding of human reaction to the environment.

The survey of 2000 office workers described by BCO (2014) show the factors which are important and those found irritating. Occupants like lots of natural light, access to outdoor spaces, contemplation spaces, feel support from colleagues; private as well as collaborative spaces. The main irritants were noise in open plan areas; lack of natural light; lack of colour, greenery and artwork; lack of fresh air; no personal control of temperature; lack of privacy; clutter; and inflexible space.

We experience life through our senses, and intelligent buildings should be a multi-sensory experience. In general, post-occupancy evaluation data show that people are very positive about spaces that are airy, fresh, have natural light, and views out onto, preferably, natural landscapes (Strelitz, 2008 ; Clements-Croome, 2006). If an environment is to be conducive to health and well-being it should display the following characteristics:

- A fresh thermal environment.
- Ventilation rates sufficient to provide clean fresh air with good distribution and acceptable levels of CO₂.
- Good natural lighting.
- Acceptable acoustic climate.
- No lighting glare.
- Spatial settings to suit various types of working.
- Ergonomic workplaces that have been designed to minimise musculoskeletal disorders.
- The landscaped surroundings should be properly considered as part of the design.
- Minimum pollution from external sources, including noise.

Personal control of these factors, wherever possible, is important. Central control for items such as security is fine, but people prefer to have some degree of control over their immediate physical environment (Ulrich 1991). The work of Boerstra et al (2013,2014) using data from the European HOPE(Health Optimisation Protocol for Energy-Efficient) Buildings project (Bluysen 2014; Roulet et al 2006) shows that occupants with a high degree of personal control over their thermal and indoor air quality environment feel they are more healthy and productive than those with a low amount of control. The increase in productivity between no to full control was concluded be at least 6%.In addition occupants were more comfortable and suffered less sick building symptoms. It should also be noted that that forms of control were more effective (e.g external shading) than others (e.g radiator valves). Often the interface between the person and the controls is poorly designed. The usability characteristic of controls needs much more consideration.

Normally we say that these factors if at acceptable levels can make a place comfortable. Later we will see that comfort alone is not enough to achieve a stimulating, creative and productive workplace. There has been an extensive body of research on thermal comfort and this was reviewed by de Dear et al. (2013).Some of the many issues discussed included:

Adaptive control (Nicol et al 2012) for naturally ventilated and air conditioned buildings is now transcending the steady state model proposed by Fanger (1970;2002);

Personal control is important: work is quoted showing that comfort, perceived health and self-assessed productivity are related to occupants perceived control through simple means like knowing that one can open a window (Leaman and Bordass 1999;2006);

Satisfaction: users dissatisfied when building and systems are over complicated with poor usability rendering personal control too complicated and unreliable (Leaman and Bordass 1999;2006);

Pleasant aspects of air movement: standards and guidelines are too conservative and are more concerned with negative aspects like drafts. Clements-Croome (1996, 2008) showed that temperature and air movement acting together can produce fresh stimulating environments. Tweed et al.,(2014) in their research on domestic properties show that the perceived need to ‘air’ the property was of prime importance.

This review by De Dear et al. (2013) is about comfort for the thermal environment only but humans perceive the environment as a whole as stimuli from many sources load the human sensory system and compete for attention.

We have to consider Indoor Environmental Quality if occupants needs are going to be met.

Air, warmth or cold, daylight, sound, space and ergonomics are all important in designing the workplace. However, in the depths of winter or at the height of summer the temperature tends to be the issue that workers comment about most frequently. However, the current sustainability agenda features energy as a highly important factor, and this is closely related to the temperature at which we maintain our buildings. A UK survey carried out by Office Angels and the Union of Shop, Distributive and Allied Workers (USDAW) (USDAW, 2006) drew the following conclusions.

- Heat exhaustion begins at about 25 C.
- 24 C is the maximum air temperature recommended by the World Health Organisation (WHO) for workers’ comfort (but note that in the UK there is no legislation covering maximum allowed temperatures).
- 16 C is the minimum temperature recommended by the UK Workplace (Health, Safety and Welfare) Regulations 1992 (13 C for strenuous physical work).
- 78% of workers say their working environment reduces their creativity and ability to get the job done.
- 15% of workers have arguments over how hot or how cold the temperature should be.
- 81% of workers find it difficult to concentrate if the office temperature is higher than the norm.
- 62% of workers state that, when they are too hot, they take up to 25% longer than usual to complete a task.

The well-established work on adaptive thermal comfort done by Nicol *et al.*,(2012) shows that the internal temperature should be chosen in relation to the monthly mean temperature. Furthermore, the study by Oh (2005) comparing conditions in Malaysian offices with those in the UK showed that people do adapt to temperature, but not to air quality. Olfactory reactions to pollutants is similar across countries.

Indoor air quality is as important as temperature (Clements-Croome, 2008). Fresh air is, like water, vital to life. A danger with sealing buildings to reduce their energy consumption is that there will be insufficient fresh air, so it is important to build in a controlled air supply such as trickle ventilators or properly located windows that can be opened a little or a lot depending on the seasonal weather. Tweed et al (2014) conclude from their research on energy in homes that many residents feel the need to 'air' their property and this can override other concerns such as heating or costs. Even in cold weather the perceived need to ventilate is a priority. Hybrid ventilation systems are common which means a fan can be used when needed but windows and doors are the most common ways people like to use when possible to encourage air flow and movement.

'Freshness' is an underused term in design, yet occupants often talk of the need for a fresh environment (Chappells, 2010). Many factors can contribute, such as colour, spatiality and, more often, air quality. Air quality is a combination of the CO₂ level, temperature, relative humidity and air movement. Chrenko (1974) researched thermal freshness using a seven-point scale, where subjects rated the freshness from 'much too stuffy' to 'much too fresh', and found that freshness was dependent on air velocity and temperature. Clements-Croome (2008) based on UK office surveys proposed a relationship between fresh air requirements and air temperature for a relative humidity range of 40–60% and average air velocities of 0.2 m/s. For a 'moderately' fresh environment, as judged by a sample of 223 UK office workers, a fresh-air rate of 2.2 l/s per person at 20C, 6.3 l/s at 25 C and 17.9 l/s at 30 C was found to be required. Environments judged by a similar population as 'very fresh' would need higher amounts of fresh air.

The link between odour and scents and work performance is less well understood, but Fisk (1999) concludes that the literature provides substantial evidence that some odours can affect some aspects of cognitive performance. He refers to work by Baron (1990), Dember *et al.* (1995), Knasko (1993), Ludvigson and Rottman (1989) and Rotton (1983). Aroma essences have been used in the air-conditioning systems in the Tokyo office building of the Kajima Corporation (Takenoya 2006).

Light is reviewed in a report by Veitch and Galasiu (2012), who cover in detail the effects on health. Daylight has a strong psychological effect on people, but reactions are linked with sensing the views out of the building, colour and spaciousness. Human perception is based on the reaction to stimuli from many sources at a particular instant. Veitch is reported by Emily Wojcik in 2012 for the American Psychological Association (www.apa.org) as concluding that when people can control their lighting levels and also colour temperature their mood is better and they experience improved well-being. One might expect that this would lead to higher productivity but Veitch does not assume this. However earlier research (Galasiu et al., 2008; Veitch et al., 2008; Veitch et al., 2010) concluded that combinations of automatic and personal control of lighting, daylight harvesting and occupancy sensors save energy and give more occupant satisfaction in open-plan offices and this leads to better health, well-being which in turn is likely to raise productivity.

The location of the building with respect to Nature is important. Ulrich (1984) showed how views out from hospital windows onto greenery improved patient recovery rates. Alvarsson *et al.* (2010) showed that the sounds of Nature aid physiological stress recovery. Greenery and still or running water refresh the body and spirit in any climate. There is growing evidence

that landscape surrounding buildings can relieve occupants stress (Beil and Hanes, 2013; Rainhaml *et al.*, 2013).

Mangone *et al.*, (2014) studied the effects on the environment of incorporating a substantial number of plants into office spaces and found that: they had a positive, statistically significant effect on thermal comfort. Interior plants can reduce buildings' operating energy consumption rates because the set temperatures for Winter and Summer can be lower or higher respectively so decreasing heating or cooling loads. Mangone's experiments showed that the presence of greenery had a psychological influence on peoples' perceptions of the environment. Other research has shown that plants can lower CO₂ levels and alter humidity enough to give a feeling of freshness. Interior landscaping has to be properly designed to be effective.

The importance of quiet areas for locating buildings and the effect on people's health has been studied by Shepherd *et al.* (2013). The surfaces of buildings set the boundaries for sound. How a building sounds is just as important as how it looks (Shields, 2003). The shape of interior spaces and the texture of surfaces determine the pattern of sound rays throughout the space. Every building has its own characteristic sound – intimate or monumental, inviting or rejecting, hospitable or hostile. A space is conceived and appreciated through its echo as much as through its visual shape, but the acoustic concept usually remains an unconscious background experience.

Buildings and systems need to be designed such that sound levels do not intrude on the activities undertaken in the space. Facades need to attenuate outside noise from entering the building. However, spaces can be too quiet, so one has to relate the sound level to the type of work being undertaken within the building.

Due to the now ubiquitous use of mobile phones, computers and other electronic equipment there is increasing electromagnetic pollution. However, the effects of this on health are still not well known (Clements-Croome, 2000a, 2004b). Computers can cause eye strain, repetitive strain injuries, poor posture and associated aches and pains, so work patterns need to include 'breaks' for users to walk, stand and move around. Desks and chairs need to be adjustable to suit the body shape of the individual.

The effect of ionisation on human health has always been debated. Nedved (2011) gives an up-to date account of the knowledge in this area.

Beyond Environmental Comfort

Perfect truth in short must realise the idea of a systematic whole (Bradley 1914)

The word 'comfort' is perhaps overused. It has a neutral but long term durable quality. It is usually seen as a pleasant or relaxed state of a human being in relation to their environment but surely that is only part of what we need for the concentrating mind? Is one highly attentive when comfortable or is there a danger of being bored, losing attention or even falling asleep? Cabanac (2006) writes about pleasure and joy and their role in human life, and indicates how transients are important in providing variety and contrast for the human sensory system to respond to. During the day we hope for and seek joyful moments perhaps a tree in blossom, pleasant air movement or changing light patterns. There is an echo of this in

Maslow's book *Religions, Values and Peak Experiences* in 1964 when he writes about peak experiences which can be transitory, momentary or longer term but trigger happiness and uplift in mood. Cabanac introduced the term *alliesthesia* which means a stimulus may give rise to a pleasant or unpleasant sensation depending on the internal state of the person (De Dear 2011). Our experience of the environment is the result of an interplay of heat, light, sound and many other factors. Buildings provide a multi-sensory experience. The senses need stimulation to react to otherwise boredom sets in.

Malnar and Vodvarka (2004) comment:

The problem with most of the research on the thermal environment is that it has centred on thermal comfort or thermal neutrality.

They go to quote other work. Wilson (1984) states: *As with the auditory area of research, the approaches concentrate on preventing feelings of discomfort, rather than producing positive responses--such as interesting, invigorating—to thermal conditions.*

Langdon (1973) commended a new way of thinking about thermal comfort by replacing a passive model with an active one in which a self-regulatory system has an open-ended interaction with the physical environment in forms governed by social constraints.

Well-being is a more comprehensive term than comfort and is perhaps defined and best summarised by Maslow (1943) in his hierarchy of needs which cover physiological, psychological, social and personal needs. Ong (2013) presents a set of essays entitled *Beyond Environmental Comfort*, which stretch the meaning of comfort into new directions. Vink (2012) in his editorial relating to comfort of products like chairs and cars for example calls for a new model for comfort based on the work of De Looze et al (2003) which is applicable to the built environment field.

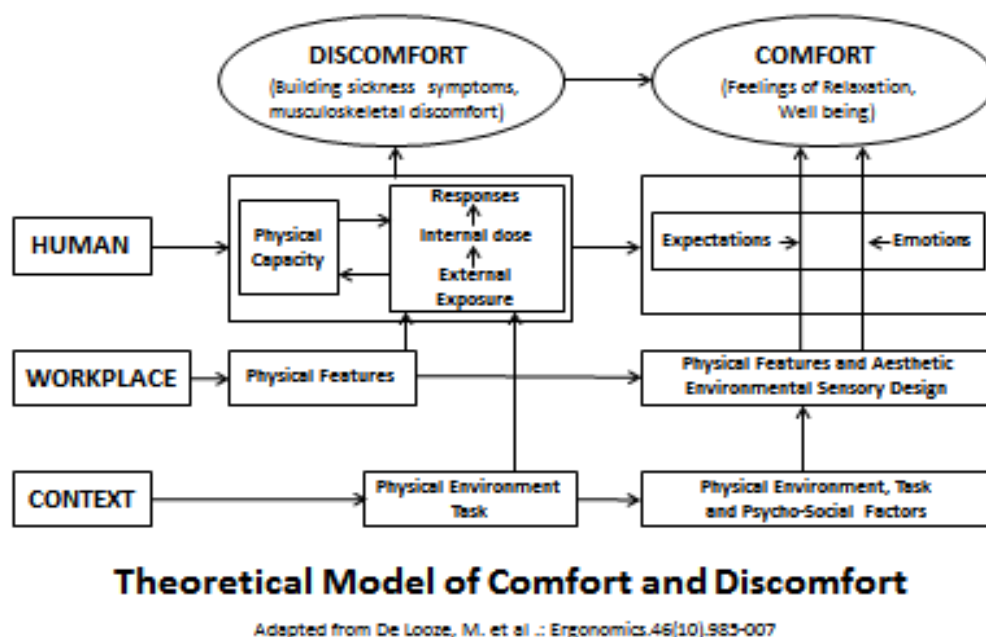


Fig 2 Adapted De Looze Model of Comfort and Discomfort (De Looze et al., 2003)

The impact of the environment on people is difficult to predict because the environment has an effect which is more than the sum of its parts (de Dear 2004; Bluysen 2014). Another complication is that sensory modalities interact. Bluysen (2014) reviews the literature on interactions between noise and heat; noise and lighting; air quality and thermal comfort. This interactive characteristic is also evident when we compare our reactions in say a black and then a white room. The same sized room can make one feel ‘closed in’ or ‘more open’. Then do the same comparison with low (feel more closed in) and high(feel more spacious) height rooms. Feelings can be affected by colour or room size in these two simplified examples but then the environment is a complex array of stimuli so measuring the overall reaction of people to it is complex. How does architecture influence our moods, thoughts and health? Lehrer (2011) reviews research that shows some unexpected links between various design factors like colour and room height for example with various aspects of work performance.

Gou et al (2014) has carried research on the gap between comfortable and stimulating illuminance settings. Levels of 400—500lux were felt to be neutral and comfortable whereas as levels above 900 lux were perceived as more stimulating for the task being undertaken. Perhaps this indicates that comfort is a backdrop which needs to be non-distracting but human beings also need sensory change from the stimuli around them brought about through the work task, the people and the built environment. It is a complex balance that needs to be achieved.

Barrett et al (2010, 2012) believes that there is no real understanding of the holistic impacts of built spaces on people despite the huge amounts of knowledge there is on individual

aspects like heat, light and sound. The outcome of his HEAD (Holistic Evidence and Design) project is the SIN Model which has three main dimensions—*Stimulation level*; *Individualisation*; *Naturalness*.

Stimulation arises from the amount of information in the setting in which triggers like colour, aromas, greenery, or things that are changing such as formal or informal social contacts or changes in the natural setting give variety, context and interest. An example of a building designed to be enjoyable and uplifting is the atrium in the Kajima office in Tokyo described by Takenoya (2006) in which aroma and bio-music are used intermittently to provide variety and stimulation. Complexity, colour and texture for example give contrast and make the environment more interesting. Over stimulation can give confusing and hectic signals which can increase stress levels whereas too little stimulation can be boring (Bluyssen 2014).

Individualisation is the occupants' personal environment and includes factors like personal control, flexibility and ones identity with a space. *Naturalness* is the basic environmental setting and this where the comfort backdrop forms an important foundation. The holistic experience is the interplay between these three dimensions of stimulation; individualisation and naturalness.

Professor Noriaki Kano (1984) proposed a model of product and service satisfaction in the 1980s which defines three essential attributes:

Threshold Attributes: customers expect these as a fundamental set of requirements (comfort criteria)

Performance Attributes: though not absolutely necessary they increase customers enjoyment

Excitement Attributes: these provide the extra sense of surprise and enjoyment (bonus factors)

These are a dynamic interactive set of attributes.

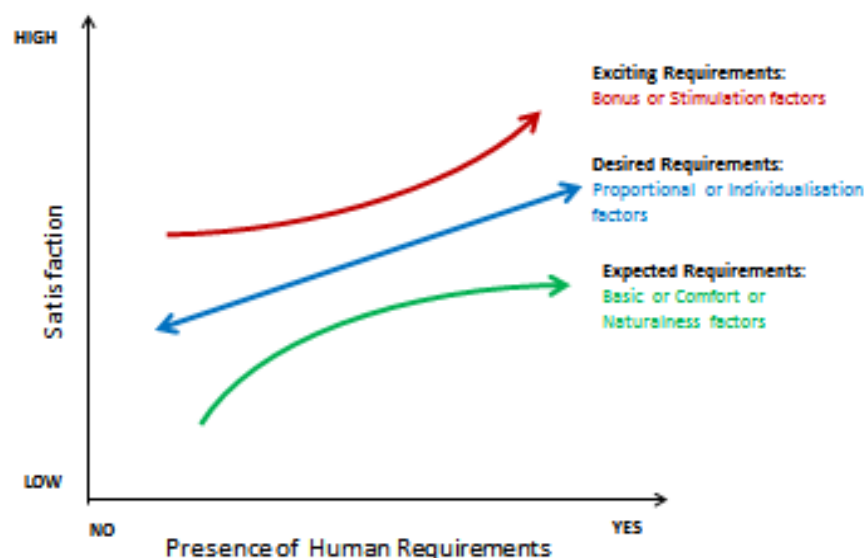


Fig 3 Kano satisfaction model adapted from Kim and de Dear (2012) and Bluyssen (2014)

Kim and de Dear (2012) adapted these and described Kanos' classification in terms of basic factors; *bonus factors* and *proportional factors*. From their survey of 351 different office buildings they identified basic and proportional factors as:

Basic factors: levels of temperature and sound; amount of space; visual privacy; flexible furniture; colours and textures; workplace cleanliness. These are minimal requirements.

Proportional factors: air quality; light; visual comfort; sound privacy; ease of interaction; comfort of furniture; cleanliness; building maintenance. Satisfaction increased linearly as these elements improved.

Bonus factors: colour, social climate, greenery, views, changing daylight, air movement. These factors act like triggers that can impact mood and add pleasure to one's experience.

One can see a connection here with the thinking behind the SIN model described above (Barrett et al 2010; 2012) as the Stimulating element corresponds to the Bonus factor in the Kano model; Naturalness corresponds to the Basic factors; Individualisation corresponds to the Proportional factors and includes personal control.

The aim of the EU PERFECTION project was to help enable the application of new building design and technologies that improve the impact of the indoor built environment on health, comfort and feeling of safety and positive stimulation (Desmyter et al 2010; Bluysen 2014). Desmyter (2010) suggested some indicators of positive stimulation which are similar to the response triggers proposed above.

We can conclude from the work described in this section that comfort is not enough. We need to continue to develop a more comprehensive view about the effects of the environment on people and widen our scope of design to produce more stimulating places for people to work in and enjoy.

The nature of productivity

For an organisation to be successful and to meet the necessary targets, the performance expressed by the productivity of its employees is of vital importance (Clements-Croome, 2006). In many occupations, people work closely with computers within an organisation that is housed in a building. Today, technology allows people to work while they are travelling or at home, and this goes some way to improving productivity. There are still, however, many people who have a regular workplace that demarcates the volume of space for private work but is linked to other workplaces and to social and public spaces. People produce less when they are tired, have personal worries, or are suffering stress due to dissatisfaction with the job or the organisation. The physical environment can enhance an individual's work and put people in a better mood, whereas an unsatisfactory environment can hinder work output.

Mental concentration is vital for good work performance. Absolute alertness and attention are essential if one is to concentrate. There is some personal discipline involved in attaining and maintaining concentration, but again the environment can be conducive to this by affecting one's mood or frame of mind; however, it can also be distracting and can contribute to a loss of concentration. Many surveys of offices (BCO 2014) show occupants requesting more

break out spaces where they can think, reflect, meditate or contemplate. This reflects the need to shut off from the ever increasing speed and volume of information flow bombarding us every day. Greenfield (2014) studies how digital technology is affecting our brains and everyday lives in terms of thinking patterns and lifestyles. Various studies at Ball State University Centre for Media Design for example show that screen time people spend on mobiles, computers, tablets and television can be as much as 8 hours per day.

A number of personal factors, which depend on the physical and mental health of an individual, and a number of external factors, which depend on the physical and social environment besides the work-related systems of management, influence the level of productivity.

Fisk (1999) has looked at the associations between the transmission of infectious disease, respiratory illnesses, allergies and asthma, sick building syndrome (SBS) symptoms, thermal environment, lighting and odours. He concluded that, in the USA, the total annual cost of respiratory infections is about \$70 billion and that of allergies and asthma is \$15 billion, and that a 20–50% reduction in SBS symptoms corresponds to an annual productivity increase of \$15–38 billion and, for office workers, there is a potential annual productivity gain of \$20–200 billion. Fisk (2000a,b) reported that, in the USA, respiratory illnesses cause the loss of about 176 million workdays and the equivalent of 121 million days of substantially restricted activity. The UK has a similar problem and the work of Black (2008) has been referred to earlier.

The World Green Council Report (WGBC 2014) states that:

Costs of ill-health vary by sector and country, and are rarely comparable, but the impact is clear:

- *The annual absenteeism rate in the US is 3% per employee in the private sector, and 4% in the public sector, costing employers \$2,074 and \$2,502 per year respectively.*
- *The cost of sickness to the employer is estimated at an average £595/employee/year in the UK, while poor mental health specifically, costs UK employers £30 billion a year through lost production, recruitment and absence*
- *The aggregate cost to business of ill-health and absenteeism in Australia is estimated at \$7 billion per year, while the cost of 'presenteeism' is estimated to be \$26 billion*

Fisk (1999) and Clements-Croome (2000a,b) stated that, in office buildings, the salaries of workers exceed the building energy and maintenance costs and the annual construction rental costs by a factor of at least 25. Evans et al (1998) concluded that business costs including salaries exceeded operating costs by 40:1 and capital costs by 200:1. This means that small increases in productivity, of 1% or less, are sufficient to justify additional capital expenditure to improve the quality of the building's services. Ultimately, this will result in a healthier working environment, as well as reduced energy and maintenance costs.

Fisk (1999) argues how poor air quality can affect the transmission of infectious disease and the incidence of respiratory illness, allergies and asthma, increase the likelihood of sick building syndrome (SBS) and decrease worker performance. Air quality plays a major role in managing these issues. Air quality is a major issue because it only takes a few seconds for air

to be inhaled and its effect to be transmitted to the bloodstream and hence the brain. Clean, fresh air is vital for clear thinking, but it is not the only issue to be considered.

The direct effects of poorly performing environments can be summarised as follows:

- Lost work hours due to sickness.
- Inability to reach true operational potential.
- Reduction in gross domestic product.
- Reduced company profit.
- A demoralised workforce.
- Increased operational and maintenance costs.
- Increased staff turnover.

The issue, therefore, becomes one of health risk and economic consequences. If organisational performance is a factor associated with the individual, then the building design should concentrate on user-centred design principles and on satisfying the occupant within the workplace.

Higher ventilation rates up to about 25 l/s per person tend to lead to reductions in sick building syndrome symptoms, absenteeism due to illness and respiratory ailments (Sundell et al 2011). Mendell et al (2013) concludes a 1 l/s per person increase in fresh air ventilation rate over the range 2-20 l/s per person is associated with a 1.0-1.5 % decrease in illness absenteeism.

In later work Fisk *et al.*, (2012) provide quantitative estimates of benefits and costs of providing different amounts of outdoor air ventilation in US offices and its effect on sick building syndrome (SBS) symptoms, work performance, short term absence, and building energy consumption. Some of the economic annual benefits were \$13 billion by increasing minimum ventilation rates from 8 to 10 L/s per person; \$38 billion by increasing from 8 to 15 L/s per person. The benefits of increasing minimum ventilation rates far exceeded any increased energy costs because the benefits yielded improved health and performance whilst decreasing absenteeism.

Roelofsen (2001) has described a study of 61 offices (7000 respondents) in the Netherlands which showed that people were off work for an average of 2.5 days/year because of unsatisfactory indoor environmental conditions. This represented a quarter of the total average absenteeism. Other work by Preller *et al.* (1990) and Bergs (2002) reveal a close correlation between sick leave and building-related health complaints.

Eley Associates (2001) found that healthy buildings lead to better work performance, and this is supported by other work such as that by Bell *et al.* (2003), Clements-Croome (2006; 2013), Fanger (2002) and Mendell *et al.* (2002). The rapid development in technology is very helpful in some ways, but it has brought with it some negative issues. These are described by van der Voordt (2003) and include getting used to technology, concentration, ICT problems and time loss associated with logging onto computer systems and searching for information.

Productivity tends to be increased when occupants are satisfied with the overall comfort of their environment (Leaman and Bordass 2006 see page Chapter 10 page 161). This is now more commonly described as when the level of well-being is high then people are generally happier, moods are positive and work focus is more likely to be intense and concentrated.

Effects of Thermal Environment and Productivity

It is probably true that most research and surveys about environmental conditions and their effects on performance have been concerned with temperature and indoor air quality. The sensors in the skin and the olfactory system receive the stimuli concerned with the thermal experience and generate the signals which pass to the brain. Much of this work is referenced in Clements-Croome 2004(a), 2006 and 2013. In this paper the emphasis is in general on later work and also the wider range of environmental factors than just temperature..

Cao and Wei (2005) described evidence which suggests that low temperatures tend to cause aggression, and high temperatures tend to cause aggression, hysteria and apathy. The question they investigated in the banking sector was ‘*Do temperature variations cause investors to alter their investment behaviour?*’ They hypothesised that lower temperature leads to higher stock returns due to investors’ aggressive risk-taking, and higher temperatures can lead to higher or lower stock returns as aggression and apathy become competing effects on risk-taking. Here we begin to see how the environment may affect decision-making evoking responses coloured by emotion. This is an issue that has been researched more recently by Satish (2011, 2012).

Cui et al (2013) carried out chamber room studies, using 36 subjects completing questionnaires and memory typing task to study the influence of temperature on human thermal comfort, motivation and performance. They concluded that learning was affected by temperature especially when it changed frequently; warm discomfort was more detrimental to performance and motivation than cold discomfort and so recommended a slightly cool to neutral setting (this would correspond to Fangers predicted mean vote PMV = 0 to -0.5). However they thought the changes in performance were due to a change in motivation than a change in temperature.

The underlying mechanisms explaining how temperature affects performance are beginning to be probed and understood. Lan et al (2011) for example found that an increase of CO₂ in the blood decreases oxygen saturation in the blood both of which are likely to affect mental work but many questions remain.

In addition to this the work of Bako-Biro et al (2012) on the effects of CO₂ on learning has been mentioned and other work referenced there and in Wargocki et al (2006), Wyon and Wargocki (2013) support the contention that the physical environment affects performance. **There remain many more questions that need research. Wyon and Wargocki identify some of these but there is enough evidence already to encourage designers to take a more holistic and in depth view of the conditions they provide for building occupants.**

Measurement of productivity

It is often said that productivity cannot be measured, but the following four approaches have had some success. In their work on the effect of environment on productivity, Clements-Croome and Li (2000) have proposed a holistic model that considers the impact of the social ambience, organisation, well-being of the individual and physical environmental factors, and

have derived relationships between productivity and job satisfaction, stress, physical environment, SBS and other factors. The data collected from office surveys using nine point scale questionnaires was analysed using the Analytical Hierarchical Process (AHP). This multifunctional approach resulted in a diagnostic tool that can be used to assess weak and strong factors in any given internal environment.

Another practical approach is given by Wargocki *et al.* (2006), who have proposed a method for integrating productivity into the life-cycle cost analysis of building services.

Yet another practical route to evaluating productivity has been described by Juniper *et al.* (2009).

Satish *et al.* (2011, 2012) have used a strategic management simulations (SMS) methodology to measure the process of thinking and the impact of environmental factors on performance. Satish believes productivity is a function of decision-making at various levels.

Reliable methodologies are evolving that will produce the evidence we need to convince clients to invest in better buildings, which will help to improve staff performance and increase value for money – bearing in mind that about 90% of the costs of running a typical commercial office building is the staff salaries.

A lack of productivity shows up in many ways, such as absenteeism, arriving late and leaving early, over-long lunch breaks, careless mistakes, overwork, boredom, and frustration with the management and the environment.

Agha-Hosseini *et al.* (2013) compared occupants' reactions to the environment in two buildings and used post-occupancy evaluation (POE) techniques to assess employees' perceived productivity, well-being and enjoyment at work. She refers to the work of Meyer (1999), Vischer (2008) and others that show how an enjoyable workplace with a stimulating physical environment can improve occupants' morale, satisfaction, perceived well-being and productivity.

Mention has been made of the survey work by Leaman and Bordass (2006) who have carried out POE over many years and conclude that when occupants are satisfied with their overall comfort then productivity tends to increase (see Chapter 10 page 161 in the above reference). The term overall comfort used here seems to be a mixture of factors including personal health and mood besides functional, convenience and environmental factors.

Lee (2006) concludes from his research on the perception k(what one actually feels or senses) and expectation (what one hopes to feel) levels of employees that when the resulting physical environment is below their expectations the occupants feel dissatisfied but if it exceeds expectation levels it does not seem to increase satisfaction. Distractions are viewed negatively and privacy positively (Ferguson and Wiseman 1986). **Lee found that the control of temperature and ventilation showed the biggest difference between perception and expectation but most importantly satisfaction with the physical environment is positively related to job satisfaction..**

Sick building syndrome

Sick building syndrome (SBS) is defined as 20% of a building's occupants complaining of a similar medical condition, while in the building, due to an unknown cause over a period of at least 2 weeks (Abdul-Wahab, 2011). Some research has questioned whether the underlying factors of SBS are perhaps biased to those who complain more than others, or those who are more sensitive and more susceptible to environmental influences. Nevertheless many surveys have shown that people can feel unwell when they are working in a building but recover when they leave it. The symptoms are usually associated with the respiratory system or they maybe cerebral (including headaches, unusual tiredness, lethargy), tired eyes or dry skin, or musculoskeletal discomfort. Symptoms may manifest as minor irritations or even as pain.

Health is the result of a complex interaction between the physiological, psychological, personal and organisational resources available to individuals and the stress placed upon them by their physical and social environment and work and home life. A deficiency in any area increases stress and decreases human performance. Research by Weiss (1997) at Rochester University in New York suggested that the mind can affect the immune system. Stress can decrease the body's defences and increase the likelihood of illness, resulting in a reduction in well-being. Stress arises from a variety of sources: the organisation, the job, the person and the physical environmental conditions. It can affect the mind and body which in turn can weaken the immune system leaving the body more vulnerable to infection caused by the environmental conditions. Stress in biological terms arises from the hypothalamus reacting to stress by releasing adrenocorticotrophic hormone (ACTH), which in turn increases the amount of the hormone cortisol in the blood to a possibly damaging level and affecting the brain cells involved in memory. This chain of events interferes with human performance, and productivity falls as a consequence.

People spend about 90% of their lives in buildings, so the internal environment has to be designed to limit the possibilities of infectious disease, allergies and asthma, and building-related health symptoms, referred to as 'SBS symptoms'. Anything in the environment that blocks or disturbs the sensory systems in an undesirable way will affect health and work performance. Thus, lighting, sound, air quality and thermal climate are all conditions around us that affect our overall perception of the environment.

Well-being

The WHO states: *'Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity'*.

The term 'well-being' reflects one's feelings about oneself in relation to the world. There is a growing interest in well-being, and in the UK well-being research centres include those at Warwick University (Wellbeing in Sustainable Environments --WISE) (Burton *et al.*, 2011); Cranfield University (Juniper *et al.*, 2009, 2011) and the Institute of Well-Being at Cambridge University (Huppert *et al.*, 2005; Anderson and French 2010).

Warr (1998a,b; 2002) proposed a view of well-being defined by two principal dimensions—arousal which may range from low to high levels and the other one is a scale ranging between pleasure and. displeasure. Together they represent the 'content of feelings' writes Warr

(2002) who goes on to propose three axes for the measurement of well-being—pleasure to displeasure, comfort to anxiety, and enthusiasm to depression. Very low arousal typifies boring environments but very high arousal describes more pressurised ones. However the questionnaires used to elicit responses are finely graduated so that respondents can express a wide range of feelings whether positive or negative covering a wide range of arousal levels.

Steemers and Manchanda (2010) have proposed another set of defining attributes that encompass health, comfort and happiness (Chappells, 2010). There are job and its' environment including cultural aspects and outside work factors that characterise one's state of well-being at any point in time and these can overlap with one another. Bluysen (2014) writes extensively about how to assess occupants well-being in buildings.

Well-being is only one aspect of mental health; other factors include personal feelings about one's competence, aspirations and degree of personal control. Well-being is connected with overall satisfaction, happiness and quality of life, and is thus a much more encompassing word than 'comfort'.

We experience life through our senses, and the environment we provide for people to interact with is important. A building and its environment can help people produce better work, because they are happier and more satisfied when their minds are concentrated on the central stimulus task which is the job in hand; good building design can help achieve this. At very low (sluggish) or very high levels (nervousness) of arousal or alertness, the capacity for performing work is low; at the optimum level the individual can concentrate on work while being aware of peripheral stimuli from the physical environment. Different types of work require different environmental settings for an optimum level of arousal to be achieved. It is necessary to assess if a sharper or leaner indoor environment is required for the occupants' good health and high productivity, and to redefine comfort as one of the defining attributes of well-being.

Work reported in the UK publication *Times Higher Education* (Newman, 2010) reviewed the impact of well-being on staff and research performance. The Higher Education Funding Council for England is encouraging universities to invest in well-being, which can reduce absenteeism and staff turnover. A report commissioned by the Health Work Wellbeing Executive, UK, stated that for every £1 spent, well-being brings a return of £4.17 (Price Waterhouse Cooper LLP, 2008); Daly (2010) has made a similar evidence-based case for hospitals.

Well-being depends on the management ethos of the organisation, the social ambience and personal factors, but the physical environment also has a major role to play (Clements-Croome, 2004a,b). Anderson and French (2010) have discussed the deeper significance of well-being, and Heschong (1979) has reported that productivity tends to be increased when occupants are satisfied with their environment. The proposal here is that well-being is achieved when all the factors in Maslow's pyramid of needs are satisfied (Table 1).

In his motivation-hygiene theory, Herzberg (1966) distinguished between 'hygiene' factors (e.g. salary, working conditions, fringe benefits), which can prevent dissatisfaction, and motivational factors (e.g. achievement, responsibility, recognition), which actually lead to improved effort and performance. Evans and Stoddart (1990) proposed a socio-ecological model of health (Figure 1) wherein the environmental and genetic sources of stimulation lead to individual responses and behaviour stemming from our state of well-being.

Need	Achieved through
Physiological catering	Good working conditions, attractive salary, subsidised housing, free
Safety	Private healthcare, pension, safe working conditions, job security
Social esteem informal	Group relationships, team spirit company sports, office parties, activities, open communication
news	Regular positive feedback, prestigious job titles, write-up in company sheet, promotion and reward
Self-actualisation opportunities,	Challenging job, discretion over work activity, promotion encouraging creativity, autonomy and responsibility

Table 1 Maslow’s hierarchy of needs in the workplace (Maslow, 1943)

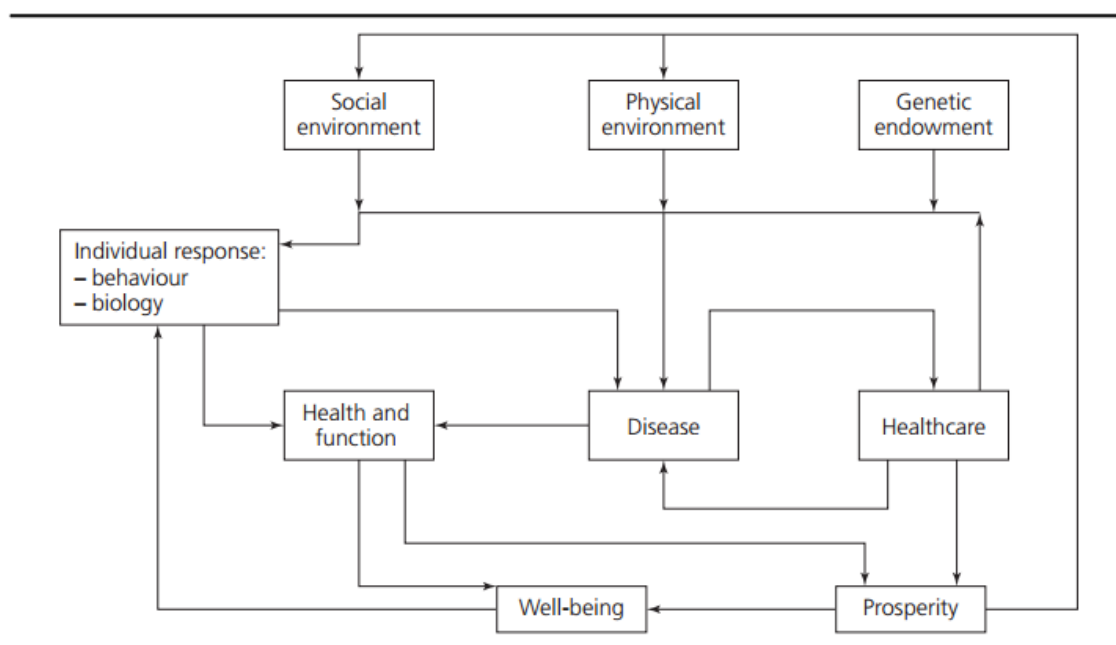


Figure 4 Evans and Stoddarts’ socio-ecological model of health (Evans and Stoddart, 1990; Morris *et al.*, 2006)

Morris *et al.* (2006) developed the drivers–pressures–state–exposure–effects–actions (DPSEEA) context model (Table 2) which is based on earlier work by the WHO which illustrated how social, economic, environmental and political drivers lead to impacts on health and well-being, and require action to improve them.

Figure 2 shows the pathway from the drivers that act on the environmental systems and result in levels or states of sound, light, heat and air quality, for example, to which human beings are exposed. This impacts on their physiological and psychological systems, and

causes positive or negative states of health and well-being. Measurements can be made to help determine what actions should be implemented.

Table 2 Elements of the modified DPSEEA context model (Morris *et al.*, 2006)

Element	Description
Drivers	Society level: social, economic or political influences on the environment
Pressures	Factors resulting from drivers that act to modify or change the environmental state
State	The resultant environment that has been modified due to the pressure
Exposure	Human interaction with the modified environment
Effects	Human health effects
Actions chain	Policy and practice designed to address particular factors identified in the
Context	Individual level: social, economic and demographic factors that influence a person's exposure to the modified environment or which lead to a health effect

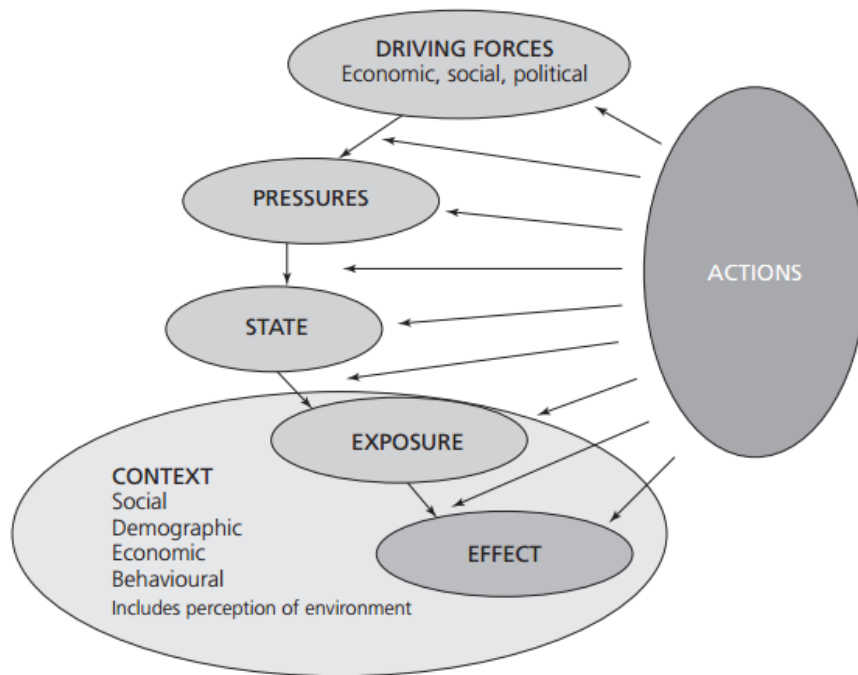


Figure 5 The modified DPSEEA context model. Reprinted with permission from Morris *et al.*, 2006, ©Elsevier

Well-being and productivity

*People crave social areas that get them bumping into each other and sparking innovation
Spaces that are more organic and fluid will always yield better creativity, productivity and at the end of the day, efficiency. Try to move from Mondrian to Miro. Parker(2014)*

Warr (2002) has described ten features of jobs that have been found to be associated with wellbeing. He believes that stable personality characteristics and age and gender are also significant. Environmental determinants of well-being are described by Warr as: the opportunity for personal control; the opportunity to use ones skills; externally generated goals; variety in the job and location; the cultural context and prospects; availability of money; physical security which includes the physical environment; supportive supervision; the opportunity for interpersonal contact; and job status in society. Warr n(2002) reviews work which indicates that greater well-being is significantly associated with better job performance, lower absenteeism and a lower probability of the employee leaving the organisation. Both the organisation and personal factors play a role.

The work of Fogg (2009) underlies the worker performance model highlighted by Heerwagen (1998) and referred to earlier in the context of occupants' behaviour with regard to energy consumption. Here it is the basis for understanding how the productivity of people in the workplace is influenced by various factors.

Performance = Motivation x Ability x Opportunity

The person has to have the ability to undertake the work; the organisation has to provide the opportunity which includes providing support systems and amenities such as interesting breakout contemplation spaces. Motivation arises from several sources. The individual must enjoy and want to do the job but the environment can enhance this by providing a stimulating backdrop with variety for them to do their work. The design of the built environment has an influence on motivation and opportunity by providing not only the functional elements but also the 'sparkle' which makes the environment enjoyable to work in (see previous section on **Beyond Environmental Comfort**).

The built environment provides a physical and social ambience that affects motivation; the provision of individual control and a healthy environment can enable ability to flourish; communications systems, restaurants, break out spaces and other amenities aid workers' motivation even further, by providing opportunities for task implementation. Earlier we referred to BCO (2014) that in their report noted that more office occupants were asking for contemplation spaces now and these require planning remembering that 'power napping' is more common besides other mindfulness approaches to refresh and aid creativity. There is also today a debate about the downsides of long sedentary work periods and the need to stand or move around which helps to avoid musculoskeletal problems developing.

Mindfulness training is about developing a constant sense of awareness and an ability to remain in the present moment often referred to as ability to focus or concentrate (Dolan 2014). The difficulty is in practice is there are a myriad distractions which disrupt concentration. Dolan (2014) writes that distraction saps attentional energy because energy is wasted switching between different things that attract our attention and goes on to say that

multitasking can make us feel as if we are more productive but actually the opposite is true because concentration requires focus on one thing at a time.

Buildings moderate climates, which helps to keep the body healthy and enhance well-being. Some buildings demand closely controlled environments, and various systems can be installed in order to achieve this, but many buildings can take advantage of the body's ability to adapt and interact in a compensatory way with other senses. Increasingly, wireless sensor networks will link a building directly with the occupant by means of sensors embedded in the building structure and in the clothing people wear. We will be able to monitor our personal reactions and responses to the environment.

If we are to understand how we can construct more productive environments we have to understand more about the nature of work and how the human system deals with work. Quality, and hence productive, work means we need good concentration. When we are about to carry out a particular task we need to settle down, get in the mood and then concentrate. When an individual is in a state of *flow* he or she may be distracted or may become naturally tired, and the process then repeats itself. Our attention span usually lasts for about 90–120 minutes and then natural fatigue comes into play and our concentration drops, but with a creative break we pick up again, concentrate for another spell of time, and the pattern repeats itself over the waking day. This is the so-called *ultradian rhythm*. De Marco and Lister (1987) have described this as a concept of *flow*. Mawson (2002) describes their work, which claims that individuals take about 15 minutes to ramp up to their concentration level. Mawson (2002) believes that there is a significant loss of productivity from distraction, which for a well-managed office has been identified by the *Harvard Business Review* (May 17th 2012) as being approximately 70 minutes of lost productivity in a typical 8-hour day. This distraction is mainly due to general social buzz and phones ringing with the subsequent conversations.

Davidson (2003; 2012) led a research study at the University of Wisconsin – Madison which showed that positive thinking (good mood, optimism) can promote good health because the body's defences (the immune system) are stronger. This suggests that the balance between the mind and the body is a sensitive one. So how relevant is this in the workplace? Various stressors can arise from conflicts within the physical, social organisational environment. People adapt to these stressors in various ways, but some will be weakened and, if conditions are very stressful, many will be affected.

There is substantial evidence, as described by Heerwagen (1998), that positive mood is associated with the physical environment and everyday events such as social interactions (Clark and Watson 1988). Even more telling is research which has shown that a positive mood aids complex cognitive strategies (Isen, 1990), whereas negative mood due to distractions, discomfort, health risks or irritants arising from the physical or social environments restrict attention and hence affect work performance. Because positive moods directly affect the brain processes (Le Doux, 1996), it can be concluded that many aspects of building environmental design can enhance task performance. Heerwagen (1998) distinguishes between direct effects, such as overheating, noise or glare, and indirect effects arising from mood and/or motivational factors. Several positive-mood-inducing factors have already been mentioned – aesthetics, freshness, daylight, views out, greenery, colour, personal control, spatial aspects and how the buildings link with Nature.

Mood, feelings and emotions affect people's decision-making. Mood can be influenced by several environmental factors, such as the 'Monday effect' or weather conditions. A body of psychological literature shows that temperature is one of the important meteorological variables that affect people's mood, and this in turn influences behaviour. Compare for example your mood on a fresh sunny day with that on a dull rainy overcast day. Cao and Wei (2005) stated that the research to date has revealed that stock market returns are associated with nature-related variables such as the amount of sunshine, the daylight-saving time change, the length of the night, and the lunar phases of the moon.

Conclusions

The internal built environment matters in all the ways that have been described in Ong (2013): it is an intrinsic part of our existence. Betthaeuser (2013) calls for a new effective and economic workplace model. His argument is that people are beginning to view their workplace in a more emotional way because the office can offset the brutality of the news media and transport stress. The workplace can be a kind of sanctuary offering safety, enjoyment and a place to fulfil creativity. He believes we need to provide a more organic and responsive place to meet occupants' needs. These thoughts are echoed in *Creating the Productive Workplace* (Clements-Croome 2006; 2000b) where a model for productivity which embraced social, personal, organisational and environmental factors together is advocated. Flexible approaches to workplace design are the hallmark of the Workplace Trends Report 2012 published by Sodexo; BCO (2014); Genslers (2013).

Good design adds value and if there is any increase in costs the payback period will be under 3 years. In addition energy and other resources will be used more efficiently and effectively.

Apple have new offices to be completed in 2016 located in Cupertino in San Francisco Bay and aspire to design and build the best office building in the world (The Times Technology Review November 2013 pages 4-5). The universal credit given to Apple products will imbue the minds of many with high expectations. The preview shows a ring structure set in a wooded landscape which will accommodate about 12,000 people. Using renewable energy and other means of being resource efficient such as 70% use of natural ventilation the building is expected to reach the highest sustainability rating levels. The interior should give occupants an aesthetic and social experience with lots of natural light and views out of Nature but also one that allows collaboration by having fluid and agile space whilst allowing the functional aspects to be highly effective. This is a building with a vision.

Step into a cathedral, a restaurant or an office and feel the ambience they offer. This can affect one's mood, well-being and work effort as an individual or as a team. Space can be patterned to encourage formal or informal working so in a way condition human behaviour. There are many subtle factors we need to know more about. For example do high ceilings encourage abstract thought and creativity as some believe (Meyers –Levy and Zhu 2007)? Often assumptions about higher occupancy densities or low ceiling heights are made on a cheap cost basis but may in the end have human consequences which make them more expensive. Designing for function and convenience alone is not enough. In the words of Volker Buscher (Director at Arup) (McMeeken 2014):

I think we are going to see the Age of the 'humane' engineer—engineers who think not just about functions but also about emotions.

After all the design is done and the building is operating there remains the person with all their unique qualities, expectations and personal habits, likes and dislikes. Shawn Achor (2010) is a passionate advocate of positive thinking and he suggests that everyone should try and make room each day for recognising some meaningful event and time for some fun, meditation, generosity, kindness and gratitude. The time spent on these actions can be small but the rewards are vast. The building can provide the setting but we as individuals have to be receptive and proactive too.

Recommendations for Planning Design and Management of Intelligent Buildings

We have defined intelligent buildings in terms of responsiveness to occupants; well-being of people; low resource consumption with low pollution and waste; flexibility and adaptability to deal with change; appropriate balance of high and low technology.. Their development is along a continuum rooted in vernacular architecture (Oliver 2008) and now moving with innovation towards buildings which are eco-effective; responsive to the occupants varying needs; are healthy and simple to operate. Old and new buildings can share this evolution. Increasingly we observe how well the plant and animal worlds can show us economies in the optimum use of energy and materials in most beautiful ways and this is leading to more examples of biomimetic architecture (Clements-Croome 2013)

Intelligent buildings should be *eco-intelligent* and this means , in terms expressed by Goleman (2009), know your impacts; favour improvements; share what you learn. In this way buildings will be equitable for all in society; have long-life value; respectful of Nature. Wherever we build we have to fulfil human needs in an evolving technological world but set in particular cultural contexts. Braungart and McDonough (2009) believe form follows evolution rather than function, but in reality both apply.

These recommendations are current guidelines but some will change and continue to evolve.

- Plan and design with an **integrated team** so that clients, consultants, contractors, facilities managers all develop a commitment to the project and want to achieve the environmental, social and economic objectives;.
- **Systems and holistic thinking** are key (Elliott 2009; Emes et al 2012).
- Assess the **impacts of the building** on occupants and communities nearby.
- **Occupants behaviour** has a large effect on the consumption of energy and water so try to increase awareness of occupants to the impact of their actions on resources. **Smart metering** is a start but **wireless sensor technology** is rapidly becoming applicable in building operation and for the use by occupants (Swan 2012). Energy reduction measures alone can lead to an energy rebound effect but considered together with the occupancy use can be effective; according to Nadel (2012) the rebound effect can be in the order reduce effectiveness of energy measures by about 20%.
- **Personalisation:** design for personal control but also encourage the use of wearable technology for occupants to develop an understanding of how their behaviour and habits can affect energy and water consumptions.

- **Coherent data management systems** are important to give feedback on the performance of different spaces in the building. Use **continual post-occupancy evaluation process** to obtain feedback data.
- Use a **whole life value** or *whole life performance* approach to ensure that quality as well as whole life costs are taken into account.
- Aim for **simplicity** rather than complexity in operation.
- Consider **well-being and freshness** of which comfort is a part. Consider all the senses and how air, views out, daylight, sound, colour, greenery and space affect us in the workplace. Design for stimulating environments not ones that continually have a neutral impact on the senses..
- **Connectivity** is important so there is **interoperability** not only between the systems and the building but also between the occupant , the systems and the building.
- Design for **flexibility and adaptability**.
- Think of an intelligent building as an **organism** responding to human and environmental needs but also one that needs to ‘breathe’ through the façade between the external and internal environments. The **façade** transfers light, solar radiation, air, noise and moisture, but also links occupants to the outside world so intelligent or smart façades allow these aspects to be controlled in a way which is functional, energy effective but also enjoyable to those working and living inside the building.
- Plan effective **facilities management** so the building, systems and occupants are cared for which also ensures low energy consumption..
- Balance **efficiency with effectiveness**. An air supply system for example can deliver the right’ amount of air to a space and be deemed efficient but may not be effective in the space because the air has no impact on the breathing zone where the people are located..
- **Design beyond the expectations defined in Regulations.**
- **Keep abreast of the relevant fields of knowledge.**
- **Learn from other sectors and disciplines.**
- Continue the quest for more **integrated education and training** so a common language and vision is inculcated in minds of students at the start of their careers. Establish the world of sustainable architecture in the minds of school children by letting them use their school buildings as a living example of sustainable resource management
- Acquire **T Knowledge** by learning in depth but also in breadth to see the interconnections with other knowledge areas.
- **Formalise learning in the workplace as well as in universities and colleges.**

Many companies today describe business intelligence in terms of being

- smart to fulfil enterprise requirements and stimulate new insights;
- by being agile with advanced integration which allows flexibility and adaptability;
- use pervasive intelligence to link strategic, economic and operational management processes.

So for example software products need to be innovative, agile and adaptable and this approach to business intelligence allows these aims to be achieved. Intelligent Buildings, old and new, need this type of thinking throughout their whole life from concept planning to care in use and beyond.

Now and the Future

The occupants of buildings often say they have little control over their environment. There is currently a debate about the need for personal carbon footprints plus a growing trend towards respecting the needs and responsibilities of the individuals who occupy and use buildings. The emergence of sensors that can be embedded into clothing, materials and equipment, together with **wireless sensor networks**, will result in a ubiquitous network providing extensive and valuable real-time data on performance. The captured data on occupants' responses to the changing environment can be analysed to reveal significant patterns that can be used to provide a degree of personal control. This will become normal practice over the next few years. Wearable electronics in clothing and personal accessories are already highly developed in the textile industry and will help people to increase their awareness of their actions with regard to energy and water consumption, for example.

Smart metering in buildings will help us to understand the influence of occupancy behaviour on consumption levels and guide people to ways in which they can reduce these levels and become more sustainable. The benefit to the domestic consumer is that they can save money, and in the case of commercial buildings organisations can encourage their staff to be more aware of green measures by offering green bonus schemes. Also, by comparing the performance of the building and its systems with the responses of the occupants, one can easily define areas of dissatisfaction and see if more appropriate design criteria may be used. It is already evident from water metering that considerable savings in consumption can be made.

The **Internet of Things (IoT)** is a wireless system which connects a whole range of things like buildings, objects and people to the internet via sensors and microprocessor chips and enables a vast array of data to be recorded and transmitted (Swan 2012). The number of devices on the internet may reach 50 million by 2050 according to Swan. Wearable computing using sensors in smart watches, wrist or headbands, augmented eyewear is evolving rapidly. Wearable sensors such as low cost disposable patches are appearing on the market. Swan (2012) reviews the present state of knowledge and anticipates a vast range of applications including how the data can be used to influence behavior as well as improve health.

Rapid advancements in information and communication technologies such as the **hafnium chip** will increase computer power and speeds of operation. Flexible fold up electronic screens will make e-material portable anywhere.

Cloud computing means virtual data storage will not only decrease computer energy cooling loads, office space and administration time but also offer the means for smart mobile devices to tap into the internet for required data. The networked world opens up a new avenue of understanding and modeling complex non-linear dynamic systems for design and management processes.

The development of **virtual reality** scenarios will allow the client to have much greater participation in design and management processes, as well as allowing greater integration between the various systems. The use of interconnect design tools will result in a more efficient and effective management process. Savings in time and

manpower and decreases in material wastage will increase the cost effectiveness of the project.

The analysis of problems in the built environment often assumes for simplicity that actions occur in a non-linear system but in reality dynamic non-linear systems predominate. **Network science** is part of the field of complexity science and chaos theory. It allows for the study of how systems interact and give rise to emergent properties and behavior (Hidalgo 2008; Lu and Clements-Croome 2010). These developments and ideas will make system modeling more realistic in the future.

Another highly significant area of development is **smart materials**, which will revolutionise the way that the building facade and the materials used for equipment can be designed. Nanotechnology is already having a large influence on the way the properties of materials can be affected by allowing modification at a molecular level, and practical examples are already being seen, such as concrete which is lighter but many times stronger than traditional concrete. It can be expected that glass will eventually become as thermally efficient as other materials. Embedded nanotubes and eventually graphene can alter the properties of the materials. Self healing building skins akin to those found in Nature are feasible. In contrast to this advanced technological approach industrial hemp is a renewable crop material which offers low embodied energy, high thermal mass, is hygroscopic and is sufficiently airtight but hemp constructions do allow a trickle of air through them. Straw, rammed earth and waste composites are other examples.

Animals and plants can teach us a lot about how to be conservative with the use of energy and materials. Rapidly we are learning about how we can use bacteria in many ways like generating electricity from plants for example. The first artificial leaf was produced in 2011 and this is a way of producing hydrogen by the action of sunlight on certain catalyst immersed in water. **Biomimetics** can be expected to offer lessons from Nature that can be applied to architecture. For some time now structural forms used in construction have mimicked those seen in plants and trees, but there is still much to learn.

Robotics offers a means of improving the maintenance and cleaning of systems. Robots can be produced on a human scale or on a nano scale and can be inserted into ventilation and heating systems in order to give feedback for maintenance schedules and to conduct internal maintenance in systems where access is difficult. The work of Otto Ng at the University of Toronto and that at the MIT Media Lab on **robotic walls** can mean spaces can be flexibly rearranged.

Attention will need to be given to the **education and training** of the design and management team. In order to fulfil social, environmental and economic requirements it will be necessary to bring these disciplines together not only by interrelating the professional bodies but also by reflecting this in the education and training of individuals. In the future we can expect to see foundation courses for architects, engineers, sociologists, economists, planners and developers before they specialise in their appropriate disciplines. The traditional design and management team may expand to include emerging sustainability specialists.

The UK National Platform for the Built Environment formulated by Construction Excellence in 2006 highlighted **resource consumption, information and communication systems, client-driven knowledge based design and construction processes** as the key issues. This has to be viewed within the grand scene for the future described in Kurzweil's book *The Singularity is Near* in 2005. The singularity is an event we cannot see beyond such as when will people be at one with intelligent machines which according to Kurzweil will be in about 2045. He forecasts that we will be able to reverse engineer the brain by 2029. Whatever the speculation the future will be challenging but affords us opportunities to improve the quality of life throughout the world. Kaku in his book *Physics of the Future* takes a glimpse at how science will shape human destiny by the year 2100 for our grandchildren..

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