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Improving Office Staff Productivity while Reducing Carbon Dioxide Emissions

Abstract

Energy costs are only a small fraction of the total overheads for offices. As such, there is little financial incentive to reduce energy consumption. However, there is growing evidence that some low energy design solutions may improve office staff productivity with no, or reduced, capital cost. Although such productivity gains cannot at present be quantified, this could be of considerable interest to the developer/owner/tenant, increasing the demand for more sustainable office buildings with reduced carbon emissions.

Introduction

The UK Government has set itself (and its citizens) commendable targets for carbon dioxide emissions. Although the indications are that it will not achieve the 2010 target of a 20% reduction relative to 1990[1], it is still determined to meet longer term targets with a 60% reduction in current emissions by 2050[2]. As is well-known, buildings are responsible for about half the primary energy consumption and hence CO_2 emissions in the UK (and other developed countries). To this end a rolling programme of improved UK building regulations (Conservation of Fuel and Power) is well underway. Office buildings are estimated to be responsible for some 2.2 million tonnes of CO_2 per year[3]. Although this currently less than 2% of the total for the UK, electricity consumption by the commercial sector doubled between 1973 and 2000[4]. This is probably due in part to the expansion of this sector and the greater use of personal computers. If the Government's 60% target is to apply to offices, how is this to be achieved?

To try to answer this question, it is instructive to make predictions about how total CO_2 emissions from offices in the UK might change depending upon future building regulations, rates of replacement of existing office building stock and expansion of the commercial sector.

The 2002 regulations set a limit of 18.5 kgC/m^2/year for air conditioned offices[5]. This is based on the current ECON 19[6] values for a "good", type-3 office. The previous ECON

19 document gave a comparable figure of 27 kgC/m^2/year (100 kgCO_2/m^2/year). If this figure reflected offices built to the then current regulations around the early nineties then this implies a reduction in the order of 30% in a decade, equivalent to about 3.5% reduction pa.

Figure 1 shows predicted CO2 emissions for the next 50 years as a fraction of current levels based on a 3.5% per annum reduction. It has been assumed that the commercial sector, and therefore the need for office space, will increase by 2% pa.; that Building Regulations will continue to be introduced every 5 years or so and that these will have the effect of reducing CO_2 emissions from new/refurbished offices by a constant percentage year on year over the whole period. Meanwhile, commercial offices are assumed to have a life of 30 years when they will be replaced or refurbished. It is also assumed that future Building Regulations will not be retrospective.

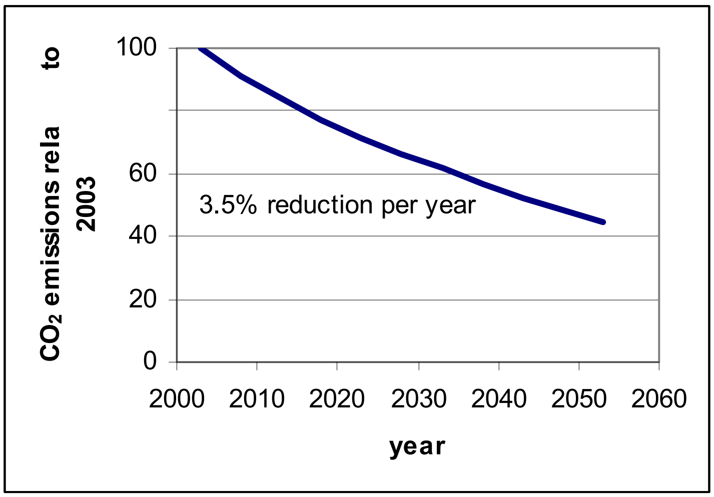

Figure 1 Scenarios for Carbon Dioxide Emissions

If we continue with a 3.5% pa reduction, emissions from the UK office sector by 2050 will almost meet the government's target.

But is it feasible to reduce CO_2 emissions from new/refurbished office buildings by 3.5% year on year? Clearly, reducing *metered energy* consumption in new/refurbished offices by 3.5% pa for nearly 50 years is a near impossible task: this would require consumption in new offices in 2050 to be less than 20% of the current value. An examination of ECON 19 shows that naturally ventilated offices typically use only about half the energy of those that are air conditioned, the main savings being in fan and lighting energy. This goes a long way towards meeting the target but, even with improving technology, it is difficult to see how this can be fully achieved. It would appear that there is a need to make more use of renewable energy in parallel with energy conservation. This is, of course, in keeping with Government policy and also that of the Greater London Authority [7] with a target of 0.7MW of commercial PV in London by 2010.

Energy Costs v Profit

How has Part L (L2) been received to date? There are of course those who see the benefits to their business of displaying a strong environmental commitment, or are genuinely concerned about our future. Unfortunately, many office buildings are designed so as to *just* comply with building regulations. It is arguable that Part L is seen by many designers and developers as at best a guarantee that it is built to high energy standards and at worst an annoying restriction. Rarely do designers treat Part L limits on energy/CO_2 emissions as the *worst case* design solution. In this respect, it is similar to speed limits: most drivers drive at, not below, the speed limit. As an incentive, we can talk of potential fuel cost savings (including Climate Change Levy and Enhanced Capital Allowance), but these are clearly not sufficiently attractive[8]. A typical air conditioned office has an energy bill of about £15/m^2/year, (based on ECON 19). This is a small fraction of the rental costs and becomes almost insignificant when compared to salary costs equivalent to about £3000/m^2/year.

To understand the true financial situation, we have to recognise that offices are built and occupied to produce a profit (or meet targets in the case of public sector) arising from the work carried out by the occupants. Energy costs are just a very small part of the overall costs of providing the personnel and office resources needed to make this profit. This energy is used to provide reasonable levels of indoor air quality, light and thermal comfort. It is perhaps not unreasonable that the office manager should assume that in order to reduce energy consumption standards of indoor environmental quality (IEQ) might fall resulting in a reduced productivity.

Yet an increasing body of evidence suggests that the opposite may be true: *better design* of office buildings can reduce energy consumption and improve productivity. This is a powerful argument for energy conservation in offices. A 25% reduction in energy consumption would average a mere £4/m^2/year saving, but an increase of only 1% in productivity could yield in the order of £100/m^2/year extra profit for the occupier. If the commercial sector can be convinced that low energy buildings can lead to improved staff productivity, this will help drive up demand.

The developer/owner will respond to this demand provided that this does not significantly increase the capital costs to rent ratio. There is anecdotal evidence that developers and investors want to future-proof their buildings but that low energy office buildings are perceived as more expensive to construct than conventional designs, (perhaps because the high profile low energy office buildings are often high quality owner-occupied)[8]. In fact, low energy design which reduce the need for air conditioning can lead to overall capital cost savings. Naturally ventilated buildings have a capital cost some 15% less on average than air conditioned[9]. Good Practice Guide 274[10] lists a number of energy efficiency measures for offices which can be incorporated at design stage together with indicative capital costs/savings. In addition, with reduced mechanical services there is less depreciation and less plant room space required.

Occupant Comfort and Health

Studies world-wide have shown a high level of occupant dissatisfaction with office environments, despite concerted efforts by building professionals. For example, Hartkopf and Loftness[11] discuss studies of offices in the USA where high occupant dissatisfaction was found.

Indoor air is often contaminated with a wide range of chemicals such as volatile organic compounds, (VOC), that we have not evolved to deal with along with concentrations of body odours and micro-organisms much higher than outdoors. Certainly, Sick Building Syndrome, (SBS), has been a major concern of office designers and occupants for some years. Fisk[12] presents data from studies in the USA that shows a reduced incidence of common infectious respiratory illness (such as colds and influenza), allergies (including asthma) and SBS with increased outdoor ventilation rates. Fisk points out that higher (mechanical) ventilation rates need not increase energy consumption if designed with improved heat recovery. Alternatively, the effectiveness of the ventilation can be increased by using displacement rather than dilution systems or, preferably, personal outdoor air supplies, (a conclusion also drawn by Fanger[13]). He notes the reduced incidence of SBS in naturally ventilated offices, (seen in many studies), but does not consider a move to natural ventilation advisable without further study.

Lagoudi[14] cites evidence from a study in Athens that outdoor air ventilation rates of less than 10L/s/person is the main cause of SBS. This is a typical *design* figure in the UK for air conditioned offices[15], though the inherent design principles of many air conditioning systems means that not every occupant receives this amount.

Bluyssen[16] et al report on the European AIRLESS project involving 56 Office buildings in seven European countries. High levels of occupant dissatisfaction were found together with poor IAQ. The conclusion was that the HVAC systems, along with building materials, were principle sources of indoor pollution. It seems that the very system which is intended to reduce indoor air pollution is itself a major polluter.

We have evolved, over hundreds of thousands of years, complex and strong physiological and psychological responses to our natural environment ie outdoors. Our eyes and thermo-regulatory system can deal not just with a wide range of illuminance, ambient temperature, wind speed etc, but rapidly changing values. This is not to suggest that we do not want to shelter from the elements – buildings allow us to inhabit a wide range of climates. The question is, how closely should we control our indoor environment[17].

Thermal comfort may well be linked to our ability as occupants to respond to the indoor environment by changing the environment itself (eg adjusting a thermostat) or our activity or clothing. There may also be a feedback process. Nicol[18] discusses research into our ability to adapt to the thermal environment. Field studies suggest a wider range of thermal comfort conditions than is currently used. This could bode well for increased use of natural ventilation where reduced temperature control is a concern. It is interesting to note that the CIBSE recommends a comfort temperature range of 22-24^{o}C in summer for air conditioned offices yet suggests that it is acceptable in naturally ventilated offices for the comfort temperature to exceed 25^{o}C for up to 5% of the occupied period (typically 125 hours per year).[19] We have evolved to expect the temperature to change with time of day, being cooler in the mornings and hottest during the afternoon. Air conditioned offices tend to follow this pattern, but the diurnal variation is small. The smaller the control band, the greater the energy consumption.

It is common knowledge that given a choice, occupants prefer a window location. This may be due to the preference for natural daylight over artificial or the view out or control over the opening of the window and blinds. A window location is reported by Hartkopf [7] to be one of the main influences on an occupant's degree of satisfaction with the indoor environment with incidences of health complaints reduced by 20-25%.

Leslie[20] claims that daylight has effect on health and that people associate daylighting with healthy buildings. Further that people also like a view out and feel more valued if near a window. A daylight factor of 2% (recommended minimum[21]) gives an illuminance of 1000 lux for much of the working year but is difficult to achieve for areas much over 6m from the window. Daylight levels nearer the windows can be ten times or more higher and have an effect on the bodies biological clock. Spending most of our time during the winter in buildings with poor daylight is certainly out of keeping with our evolution. Muneer et al cite the need for a daily dose of daylight of at least 1000 lux for one hour[22] It is believed that significant numbers of people suffer from Seasonal Affective Disorder (SAD).

Flicker from fluorescent lighting, operating at 50Hz, is believed to cause headaches for some people. At the same time, of course, windows can cause significant glare problems at times of high outdoor illuminance and particularly direct solar gain.

In the final report on the Probe studies carried out in the UK[23], the authors report that higher levels of occupant satisfaction are easier to achieve when buildings are designed as shallow plan with occupants having views out and control over openable windows. This is not to say that buildings without these features cannot achieve high levels of occupant satisfaction. One of the best performing office buildings studied in terms of occupant satisfaction was deep-plan and air conditioned. The success of this building was put down to good design supported by good facilities management. The relatively high summertime temperatures is also a cause for concern in naturally ventilated offices. A 'cool' environment is claimed to be viewed by occupants as a sign of a healthier environment, (also supported by Fanger). The building given the highest comfort score was a shallow plan, mixed mode building using the termodeck system, though this was an academic, not commercial, office building.

Effects on Productivity

Fisk suggests that absenteeism due to respiratory illnesses can be reduced by about 20% (35% in one study) by increasing the outdoor ventilation rate. Taking an average rate of absence due to such illnesses of 3 days per annum out of a total of about 230 this implies an increase of 0.26% in attendance. SBS reduces productivity at work and possible absence. Fisk suggests that reductions in the incidence of SBS of up to 50% is achievable resulting in productivity gains of another quarter percent. There are also productivity gains to be made from reducing incidences of allergies and asthma.

Fisk also makes mention of studies that have shown that doubling of ventilation rates increases worker task efficiency by some 2%. This is not the same as productivity increasing by 2% but does suggest a significant increase.

Productivity is believed to be increased by daylight though the quantitative effect is not known. Daylight leads to higher indoor illuminances than is achieved by artificial lighting for much of the time. The indoor illuminance used to design the artificial lighting scheme is a compromise between productivity and cost. Higher illuminances tend to improve visual performance (though the law of diminishing returns quickly takes effect) and older people certainly require more light! Higher background illuminance may conflict with the use of VDUs however, requiring brighter screens and higher energy consumption. Glare is also a potential problem with daylight.

There is also the photobiological effect on our circadian cycle and manufacture of vitamin D together with the photopsychological effect on our mood. The spatial and temporal variations of illuminance resulting from daylight are also appreciated by people. Given the strong preference for natural light shown by the majority of people, it is difficult to imagine that daylight does not improve productivity provided, of course, that glare is avoided. The 20-25% reduction in health complaints (Hartkopf) by occupants with window seats supports this.

The effect on productivity of thermal comfort is also not quantifiable. Indices have been based on comfort rather than productivity and much of the research has been carried out in artificial, laboratory environments rather than working environments. Thermal comfort is influenced mostly by radiant and air temperatures and air velocity. Windows can create 'radiation' draughts in winter due to the cold surface, (though the high thermal performance of modern glazing systems has greatly reduced this), and convection draughts when opened for ventilation. Natural ventilation can result in high comfort temperatures in summer. At the same time, windows can provide a change in thermal conditions (radiant and air temperature and air velocity) throughout the day which might improve perception of comfort.

Motivation is recognised as an essential factor in improving productivity and is almost certainly influenced by the occupant's perception of how highly valued s/he is by the employer. Occupants who are dissatisfied with their working environment might therefore show *reduced* productivity for psychological rather than physiological reasons.

In a survey of some 300 office staff[24], there was a consensus that comfort was important in 'being able to deal with stress, stay focused and feel good about what they do' with 41% feeling that comfort was the most important factor, (though what was meant by comfort was not defined). Being able to modify one's environment implies a higher status in an organisation, hence the preference for a window location.

Further, an employer who is clearly concerned about the working environment is likely to more easily attract and retain staff. Recruitment costs are in the order of £2000 per person for junior staff. On the basis of such staff changing jobs on average once every five years this alone is equivalent to a cost of £40/m^2/year. In the office staff survey mentioned above[24], the workplace environment was identified as playing an important role in deciding to take or stay in a job.

Implications for the Design of Offices

More daylighting and access to windows implies shallower floor plans are used. This, in turn, raises the opportunity to utilise natural ventilation. Despite these being the 'traditional' method of providing light and air, the design needs careful attention. Potential problems of excessive summertime temperatures, high mean radiant temperatures, draughts, glare and noise need to be addressed.

The high summertime temperatures can be reduced with the intelligent use of night time ventilation and (exposed) thermal mass. There is increasing interest in 'mixed-mode' operation[25] whereby mechanical cooling is provided only when needed to selected areas of the building or for a few weeks each year when outdoor air temperatures are high. Mechanically assisted ventilation can also be utilised in summer when wind speeds are lower and there is insufficient stack effect to drive the natural ventilation.

Solar radiation falling on occupants increases the perceived comfort temperature (dry resultant) by more than 1^{o}C per 100W/m^2. This is of course a problem for air conditioned offices as well. The problem is particularly acute on East and West facades where external shading is less effective. Solar control glazing which reduces light transmittance is not a particularly good solution as daylight levels fall and view out is reduced. Light shelves in combination with occupant controlled blinds can reduce discomfort and glare whilst directing useful daylight deeper into the building.

Shallow plan will not meet all requirements, however. The need for offices in the City of London with very large footplates has been identified[26] to accommodate the larger commercial organisations. This implies both deeper plan and taller buildings. Deeper plan raises questions of reduced daylight and view out and its negative impact on productivity. Even so, some use of natural ventilation/mixed mode is possible on deep plan[27]. Tall buildings are often seen as unsuitable for natural ventilation due to high wind speeds on upper floors though there have been success stories, for example the Commerzbank, Frankfurt.[28] This 56-storey tower has been monitored since completion in the late 90's and has exceeded the designers predicted energy savings. The building is naturally ventilated for much of the year using atria and 'sky-gardens'. It should also be pointed out that the climate in Frankfurt is more extreme than in the UK.

Useful advice on the design of low energy, high productivity offices is available in an IPMV document[29], and on creating high levels of occupant satisfaction in the Probe Report. This latter emphasises the need for making the operation of buildings environmental controls simple to understand and easy to carry out by the occupants.

Natural ventilation is subject to weather conditions, unlike mechanical air conditioning. The latter is well understood by engineers who are confident in their ability to design and size such systems to provide the internal comfort conditions and fresh air ventilation rates specified. This is not so with natural ventilation. Useful guidance does exist, in particular the CIBSE AM10[30] but this does not provide the engineer with the level of assurance afforded to air conditioning design. At present, naturally ventilated buildings must be modelled using sophisticated thermal simulation software and CFD to determine performance under a range of weather conditions. If natural ventilation is to become the norm for offices, we need a more straightforward method of design and, most importantly, an industry standard method.

Embedded renewable energy will be more of a challenge. Currently, the only option for city centre offices is limited, with photovoltaics (PV) being the prime candidate. The cost of this technology is commercially prohibitive, but a combination of increased demand and improvements in manufacturing techniques are bringing this down, and commercial viability (in its simplest form) is now realistically achievable within the next decade. Other urban opportunities for renewables include biomass fired combined heat and power plant, the use of small wind turbines (perhaps with a resurgence in vertical axis technology), and the use of solar thermal collectors for hot water services. In the longer term there is the prospect of hydrogen-fuelled fuel cells, with the hydrogen being produced from intermittent renewables such as PV or wind. This latter option is currently a long way from the market, but projections for the viability of such a technology are certainly within the 2050 time frame.

Of course, it is possible for organisations to invest in remote renewable energy capacity that offsets the fossil fuel use within their city-centre buildings. This has great potential and has been used by well-known names such as Body Shop for some time now. Unfortunately, this is not within the scope of the current building regulations. Perhaps it is time that this option for meeting carbon emissions was considered.

Conclusions

We need to continue reducing carbon emissions attributable to energy consumption in new and refurbished offices by about 3.5% per annum if we are to be close to achieving a target 60% reduction in this sector within 50 years. This will require a new office in 2050 to consume only about one-fifth of the non-renewable energy of present day designs. This can only be realistically achieved by the increasing use of renewable energy and a move towards more widespread use of natural ventilation and daylight. Prospects for renewable energy are improving, albeit slowly. In comparison, a naturally ventilated or mixed-mode office typically consumes about half that of an air conditioned office and could be cheaper to construct overall.

Energy costs are an increasingly small fraction of total running costs offering little financial incentive for the occupant to look beyond the minimum standards set by the building regulations. But some aspects of natural ventilation and daylighting could increase productivity, holding out the promise of financial gains far in excess of any from energy conservation. Although it is not possible at present to quantify such productivity gains, (or even prove conclusively that they exist), there is increasing, if circumstantial, evidence that such gains are likely. In particular

- A reduction in SBS in naturally ventilated offices
- A 20-25% reduction in health complaints from occupants with window seats
- The common view that daylit offices are healthy offices
- A preference for naturally ventilated offices and natural daylight

The potential for increased productivity might in some cases be due to an occupant's level of satisfaction with his/her work environment, and hence motivation, rather some quantifiable physiological link. Though there is believed to be a link between levels of natural daylight and health.

The design of naturally ventilated offices will not meet all requirements. Mixed-mode may be more appropriate in some cases. Designing for natural ventilation is not as well understood a process as for air conditioning and requires more sophisticated software to analyse the building response. Ventilation rates are not guaranteed. There is a potential problem with noise ingress. Increased daylighting could lead to thermal and visual discomfort if the windows are not appropriately designed. Despite this, there are many examples of successful naturally ventilated and mixed-mode offices.

We surely have a responsibility to inform our clients of the possible advantages of natural ventilation and daylight in terms of occupant satisfaction and productivity and the bonus of the reductions in carbon dioxide emissions.

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[1] Achieving a Better Quality of Life, Review of Progress Towards Sustainable Development, UK Government Annual Report 2002, Feb 2003
[2] UK Government White Paper, Our Future Energy- Creating a Low Carbon Economy, Feb 2003
[3] BRECSU, 15th March 2003, www.action-energy.org
[4] J Wade and J Pett, Energy Efficiency in Offices: Assessing the Situation, Association for the Conservation of Energy, March 2003, www.ukace.org
[5] Building Regulations Approved Document L2 (April 2003)
[6] Energy Consumption in Offices, Best Practice Programme, BRECSU 1999
[7] Draft Energy Strategy, Greater London Authority, Jan 2003
[8] J Wade and J Pett, Energy Efficiency in Offices: Motivating Action, Association for the Conservation of Energy, March 2003, www.ukace.org
[9] CIBSE Applications Manual A10: 1997, Natural Ventilation in Non-Domestic Buildings.

[10] Good Practice Guide 274, Environmentally Smart Buildings – a quantity surveyors guide to the cost effectiveness of energy-efficient offices, Best Practice Programme, BRECSU, 1999
[11] Hartkopf and Loftness, Global Relevance Of Total Building Performance, Automation in Construction v8 (1999), Elsevier
[12] Fisk W J, Health and Productivity Gains from Better Indoor Environments and their Implications for the US Dept of Energy, E-Vision 2000 Conference Wahington DC
[13] Fanger P O, Human Requirements in future air conditioned environments, International Journal of Refrigeration v24, 2001.
[14] Lagoudi A et al, Symptoms experienced, environmental factors and energy consumption in office buildings, Energy and Buildings 24 (1996), Elsevier
[15] CIBSE, Guide A, Environmental Design, Section 1: Environmental Criteria for Design, CIBSE 1999
[16] Bluyssen PM et al, Why, When and How do HVAC systems pollute the indoor environment and what to do about it? The European AIRLESS project, Building and Environment v38, 2003
[17] Baker N, We are all Outdoor Animals, Architecture City Environment, Proc. PLEA 2000, ed Steemers K and Yannas S, James and James, London, 2000
[18] Nicol J F, Humphreys M A, Adaptive thermal comfort and sustainable thermal standards for buildings, Energy and Buildiongs v34, 2002
[19] CIBSE Guide A, Environmental Design, Section 1: Environmental Criteria for Design, CIBSE 1999
[20] Leslie R P, Capturing the Daylight Dividend in Buildings, Building and Environment v38 (2003), Pergamon
[21] CIBSE Code for Interior Lighting, CIBSE 1994
[22] T Muneer, N Abodahab, G Weir and J Kubie, Windows in Buildings, Architectural Press, Oxford, 2000
[23] Probe Final Report 4, Strategic Conclusions, 31st Aug 1999,
[24] Workplace Values, How Employees Want to Work, American Society of Interior Designers, 2001, www.asid.org
[25] General Information Report 56, Mixed-mode buildings and systems, Best Practice Programme, DETR,UK
[26] London Office Policy Review 1997
[27] Market Value, Building Services Journal, March 2003
[28] See Roger Preston & Partners Website: www.rpreston.com
[29] Concepts and Practices for Improved Indoor Environmental Quality, International Performance Measurement and Verification Protocol, March 2002, www.ipmvp.org
[30] Applications Manual AM10, Natural Ventilation of non-Domestic Buildings, CIBSE, 1997