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HEALTH AND WELLBEING SPECIAL

BUILDING PLANT

To what extent can ferns, lilies and corn plants improve indoor air quality?

EVALUATING DYNAMIC OFFICE LIGHTING

PERFORMANCE-BASED TARGETS AT DELOITTE'S LONDON HQ

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Best of health

Workplace wellbeing can no longer be ignored or treated as a box-ticking exercise. A recent YouGov survey of more than 2,000 British employees found that fewer than half (43%) believed the design of their workplace encouraged innovation and creativity. Temperature, lack of natural light and noise levels were found to be the biggest wellbeing concerns for office workers, with more than a third (36%) saying they would be less likely to take sick days if they worked in an inspiring environment.

Creating a human-centred workplace, where the health and wellbeing of staff is paramount, was the brief for Deloitte's new UK HQ at One New Street Square in London (see page 8). The building achieved exemplar levels of air quality, which – as Julie Godefroy points out on page 4 – is an area of focus in the upcoming TM40. The updated document focuses on building performance outcomes, setting out health-based metrics to better inform projects and encourage a more rigorous common language.

Whether 'circadian' lighting improves alertness is another area that has prompted debate; on page 18, BRE researchers shed light (pun intended) on an experiment that attempts to find out.

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CIBSE Journal is written and produced by CPL (Cambridge Publishers Ltd) Tel: +44 (0)1223 378000. **www.cpl.co.uk**
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Editorial copy deadline: First day of the month preceding the publication month

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A rigorous exercise

CIBSE's upcoming TM40 includes new performance criteria definitions for health and wellbeing. CIBSE's Julie Godefroy says designers should target specific outcomes and use health-based metrics to ensure everyone is speaking a common language

The past decade has seen significant advances in our understanding of how environmental factors affect our health and wellbeing, and in design solutions in the built environment. Combined with worldwide trends such as increased life expectancies, ageing populations, pressures on healthcare systems and the growth in urban living, these developments have prompted a significant revision of CIBSE guidance on health and wellbeing considerations in building services – Technical Memorandum 40 (TM40) *Health and Wellbeing*.

TM40 is now in the final stages of production, and this article summarises one aspect: the approach for defining indoor environment criteria for health and comfort. The TM will also include guidance on design, construction and operation. For an overview of the revision, see *CIBSE Journal* March 2018 (**bit.ly/CJJun19TM401**). Regular updates are provided at the CIBSE Knowledge Portal (**bit.ly/CJJun19TM40**).

Defining performance

A significant update in the TM is the focus on building performance outcomes – for each environmental factor (light, humidity, thermal condition, and so on), the TM summarises existing health-based guidance and regulations, and proposes recommended levels accordingly. These levels may be used as targets – for example in new buildings, fit-outs and refurbishments – or as benchmarks in existing buildings to define priorities and short-to-longer-term improvement programmes.

In some areas such as air quality, this is a

> "This TM intends to set out clearly health-based metrics to better inform projects and encourage a more rigorous common language"

significant shift from the current approach – the term 'air quality' is often used when actually referring to design measures (ventilation rates); indicators, for example, total volatile organic compounds (tVOCs); or occupant perceptions, for example smells, and complaints of 'stuffiness', as illustrated in Figure 1.

Ventilation and indicators without consideration of potential indoor and outdoor pollutant sources are no guarantee of good indoor air quality. Similarly, while occupant feedback is useful to gauge comfort and satisfaction, it does not guarantee health-based outcomes. A stark example is carbon monoxide, which can be lethal but is not detected by human senses.

This TM intends to clearly set out health-based metrics in order to better inform projects and encourage a more rigorous common language. It also recommends avoiding the term 'sick building syndrome', which covers a range of possible symptoms and causes, rather than being specific about what the problem – and therefore the solution – may be.

For health purposes, as a very minimum, it recommends meeting regulatory requirements and internationally recognised health-based guidelines from the World Health Organization (WHO) or its recognised agencies, as in the case of electromagnetic fields. This is broadly consistent with other emerging guidance, such as BS ISO 17772, 2018, and the revised BB 101: *Ventilation, thermal comfort and indoor air quality 2018*.

In many cases in the UK and EU,

Design measures → **Desired IEQ outcomes**

Perception and satisfaction → **Health-based metrics**

Indicators (eg tVOC) → **Pollutants (eg formaldehyde)**

Figure 1: TM40 approach to performance criteria

regulations incorporate – and are more onerous than – WHO guidelines. However, a notable exception is indoor air quality, where there are currently no comprehensive regulations; professionals are therefore strongly advised to refer to WHO guidelines.

For comfort purposes, the recommendations in the new TM largely follow existing best-practice guidance. They stress the importance of user choice and control over their environment, to take account of individual sensitivities and preferences, which increase the likelihood of high comfort and satisfaction levels. This is not a new recommendation, and a large body of evidence from decades of post-occupancy evaluation supports it.

Looking ahead

There is still much ongoing debate, research and development. Professionals should be aware of the current limits of knowledge in some areas and, where appropriate, should seek opportunities for innovation, collaboration with academia, and adding value for their clients.

One very active area is research on the impact of indoor environmental factors on cognitive performance, particularly in commercial offices. Studies vary greatly in quality – often, those that appear to offer new findings merely reiterate existing guidance, because the improvements in performance are shown by comparison with poor quality environments. Figure 2 illustrates recommendations from the TM on how to approach these studies.

Two of the main debates concern what should be the right limits for internal CO_2 levels, and how to define and design for 'human-centric' lighting.

Traditionally, internal CO_2 level has been seen as indicator of ventilation effectiveness rather than a pollutant in itself, except at very high levels. There is no WHO guideline limit on it, and UK regulations have occupational exposure »

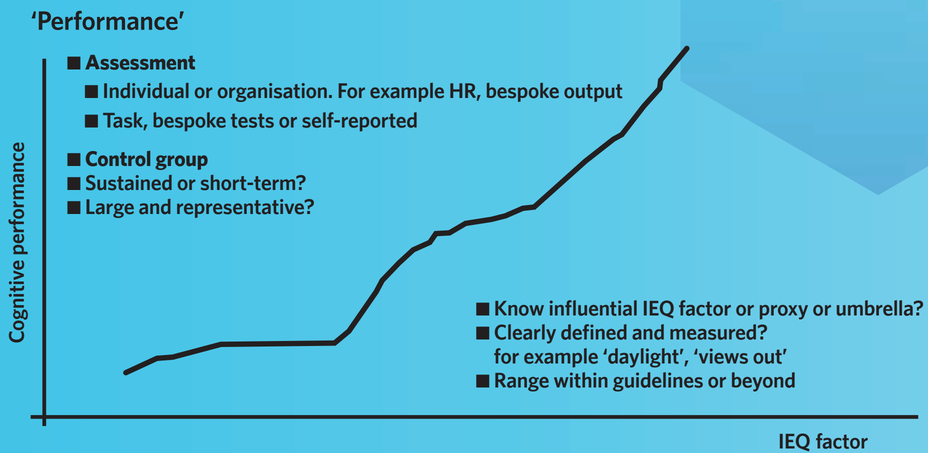

Figure 2: Studies on indoor environmental factors v cognitive performance: tips on what to look out for

> "Advances in our understanding of non-visual effects of light on our health and alertness have prompted much debate"

» limits (COSHHH – WEL) to prevent high CO_2 levels leading to headaches, dizziness, confusion and loss of consciousness (5,000ppm for an eight-hour exposure and 15,000ppm for a 15-min exposure).

Many studies on the impact of indoor air on cognitive performance focus on ventilation rates, which makes it difficult to attribute changes in cognitive performance to CO_2 levels on their own, as a range of other factors may vary with ventilation.

However, recently a small number of studies have ensured that CO_2 levels were the only variable by keeping ventilation rates and all other parameters the same, and simply introducing higher CO_2 levels into the supply air. Most – but not all – tests show an impact on cognitive performance at increased CO_2 levels, in particular on decision making, indicating that CO_2 has an impact in its own right, and at lower levels than may have been assumed in the past.

However, it is also important to note that the levels at which significant effects are reported are well above existing best-practice guidelines, in the range of 750 to 900ppm.

Another very active area of research is 'circadian', or 'human-centric' lighting, where advances in our understanding of the non-visual effects of light on our health and alertness have prompted much debate about what the right metrics and levels should be. There is a general consensus that traditional measures of light, such as illuminance, are inadequate to represent the non-visual impact of light, and new metrics are, therefore, needed.

However, what these new metrics should be is still debated because of the complexities of our responses, interactions between different light receptors in our eyes, and time factors, which mean that a single light condition is not linked to a single response. There is no wide consensus yet; in the meantime, good design principles should be followed by seeking to give priority to daylight and views out (with glare control). It should be completed by electric lighting, which again should follow guidance from the SLL, including on parameters such as spectrum distribution, colour rendering and products.

Finally, an important conclusion from the evolving knowledge is that, in current projects, we should follow the precautionary principle to avoid unintended consequences, as those mainly only manifest themselves in the long-term – as in the case of asbestos and lead paint. This does not prevent innovation, but encourages a cautious review of claims, and possible effects, with monitoring and evaluation to keep new uses under review. **CJ**

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Responsibility for energy and environment

Air apparent

Health and wellbeing was of utmost importance in the development of Deloitte's new UK HQ. Achieving both Well Certified Gold and Breeam Outstanding ratings, Hoare Lea's Sam Carlsson explains how a performance-based target was key to getting the design team engaged with IAQ on the project

The health and economic impacts of poor air quality within urban areas and inside buildings is becoming increasingly apparent, and mitigation measures are currently a key focus area for policymakers and those involved in designing the built environment.

One New Street Square is Deloitte's 25,800m^2 UK headquarters, a workplace for 5,500 staff and providing facilities for their 13,000 strong London campus. The brief was simple: design this landmark HQ to lead the way in providing an environmentally sustainable and human-centred workplace, where the health and wellbeing of the staff is paramount.

The fit-out was completed in 2018 and was the first in the world to achieve both Breeam Outstanding and Well Certified Gold ratings. It is also the largest Well Certified Gold commercial interior globally to date.

With a human-centric approach to design and performance-based targets set by the Well Building Standard, delivering a building with exemplar levels of air quality was a core principle of the design, from the brief through to operation. Suggested indoor air quality (IAQ) parameters are defined in various industry guidance. See 'Air quality parameters' box below for the parameters required by the Well Building Standard (v1)[1] that were adopted in this project.

To achieve these levels, detailed design, construction and performance measures were undertaken at each stage of design and construction.

Measures

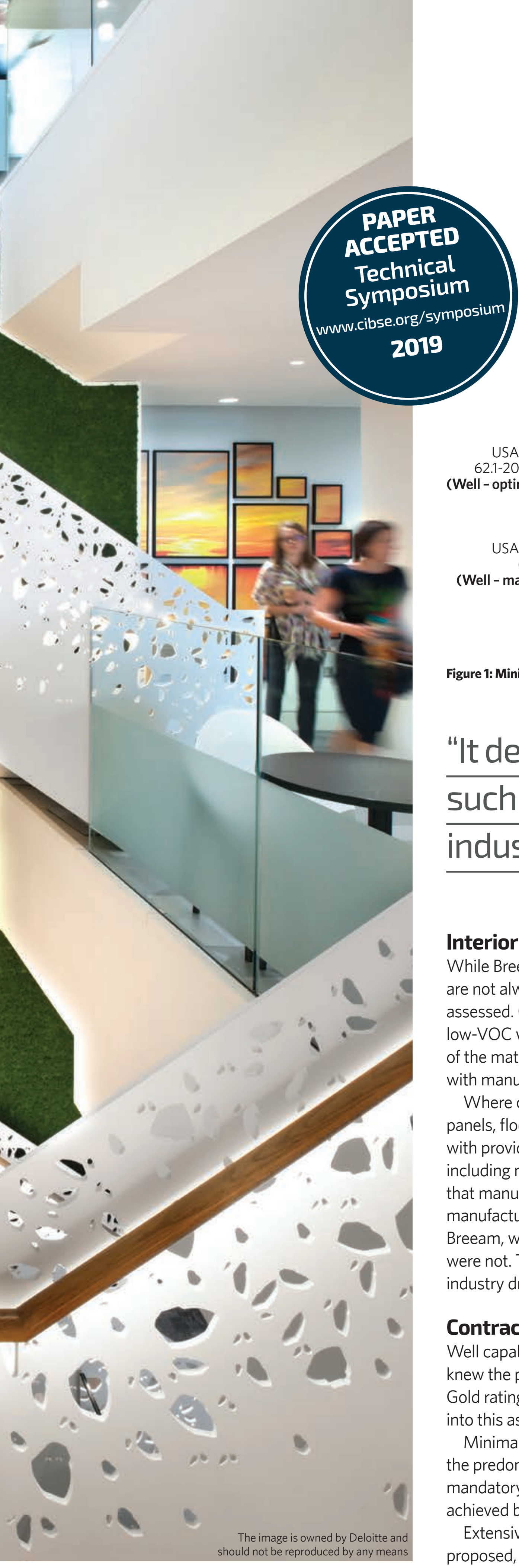
During the early stages of design, a comparison of ASHRAE 62.1 (2013) outdoor air supply standards (used as part of the Well guidance) with UK benchmarks was undertaken. This found that, compared with Well guidance, much higher ventilation rates are expected in UK Building Regulations and industry guidance, such as that from the British Council for Offices (BCO) and CIBSE (see Figure 1).

In terms of air filtration, Well recommends filtration levels of MERV 13 to filter outdoor air, equivalent to ISO ePM2.5 >65% (previously F7 filter), which are typical for commercial projects in London.

Understanding that outdoor air quality varies with location, the latest version of Well (v2) has introduced a tiered system based on measured outdoor air quality data. The annual average outdoor PM2.5 level on Farringdon Street, near the One New Street Square building, is 16μg·m^{-3}, which is below the Well v2 tier threshold for MERV 13 filters. However, filtration still needs to account for pollution events, so balancing filtration levels with energy consumption is key.

AIR QUALITY PARAMETERS

Formaldehyde levels <27ppb
Total volatile organic compounds (tVOC) <500μg·m^{-3}
Carbon monoxide <9ppm
PM2.5 <15μg·m^{-3}
PM10 <50μg·m^{-3}
Ozone <51ppb
Radon 0.148 Bq·L^{-1}



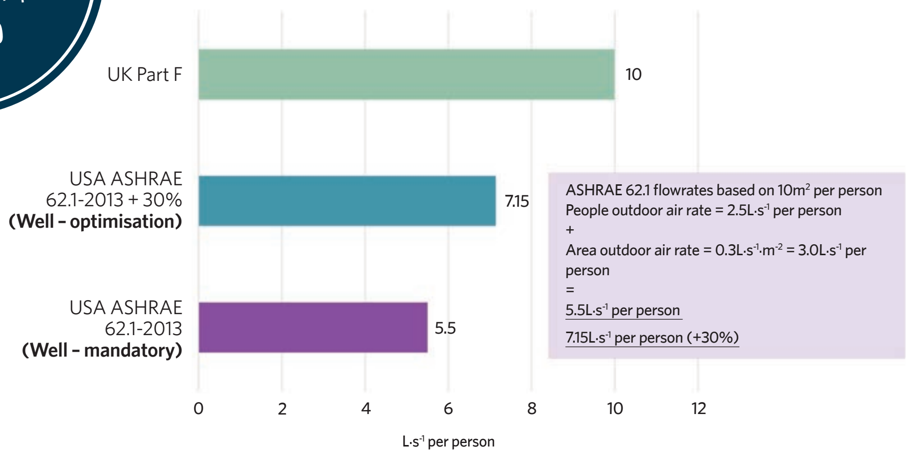


Figure 1: Minimum outdoor air rates

> "It demonstrates that assessments such as Breeam and Well can be industry drivers for change"

Interior material selections

While Breeam has voluntary credit requirements for low VOC materials, these are not always pursued, and the criteria do not call for all material types to be assessed. Given the performance-based targets, ensuring that all materials were low-VOC was essential at One New Street Square. This involved detailed analysis of the material selection process with the architect, as well as engagement with manufacturers.

Where categories overlapped with Breeam (decorative paints, carpets, wood panels, flooring adhesives, and so on) manufacturers were generally able to assist with providing VOC certification. However, when assessing new categories, including non-decorative paints, insulation and all other adhesives, it was clear that manufacturers had not been asked for this information before. For example, manufacturers of flooring/wall covering adhesives, which are assessed under Breeam, were able to provide VOC certification; however, other manufacturers were not. This demonstrates that assessments such as Breeam and Well can be industry drivers for change.

Contractor measures on-site

Well capability was part of the tender process, to ensure any appointed contractor knew the project brief included delivering a Well-certified building, and targeting a Gold rating. As with the rest of the design team, the contractor, Overbury, bought into this aspiration from day one.

Minimal data exists on the impact construction practices have on IAQ, with the predominant source of data deriving from projects that have pursued a non-mandatory Breeam credit. Therefore, establishing the level of IAQ that could be achieved based on standard construction procedures was challenging.

Extensive dust control measures, over and above best practice, were originally proposed, increasing the overall construction budget. A project team roundtable » concluded that these measures may not be necessary and, instead, an iterative testing process was introduced to ensure the performance outcomes were achieved.

The contractor ensured all subcontractors received introductory Well training, highlighting the importance of the performance-based outcomes. This also led to the introduction of a 'product gate guard', with powers to confiscate any non-approved products. A list of approved adhesives was also signposted around the site.

Another measure to remove and reduce the level of VOCs and particulates introduced during construction was to carry out ventilation flush-outs. These occurred throughout construction, upon handover, and during initial occupancy.

Furniture selections

In terms of VOC certification, the project team found the UK/European furniture market to be in its infancy. However, given the size and scope of the development, many manufacturers were willing to get their products tested to be used on the project, again demonstrating how assessment methods can be drivers for change.

However, with significant levels of bespoke furniture, it was not always possible to produce the level of certification required by Well. For this remaining furniture – approximately 20% by cost – a detailed analysis of the materials used in the manufacturing of the products was undertaken to demonstrate that the furniture met the intent of the criteria and would not jeopardise the overall air quality of the space.

By analysing the material breakdown, the team was able to identify non-approved products and, in some instances, discuss and convince manufacturers to use compliant products (for example, adhesives). This led to factory tests being undertaken to demonstrate that neither quality nor warranty was compromised when using approved products.

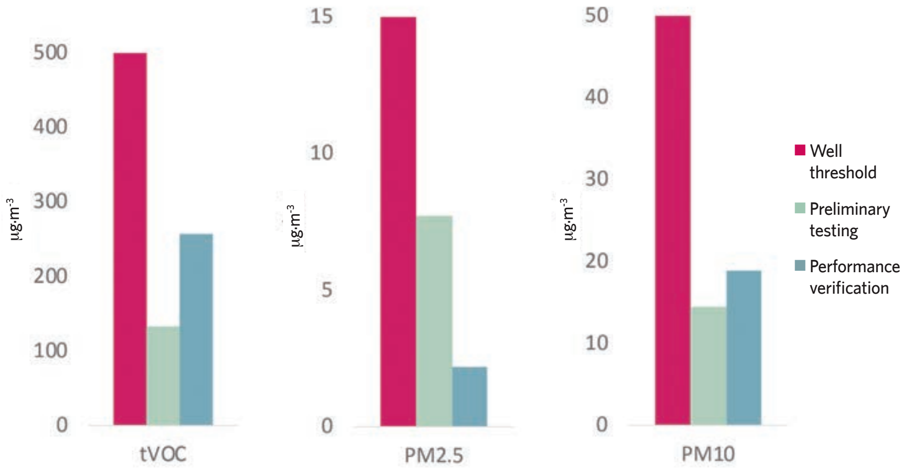
Pre-handover testing

To ensure compliance with the performance-based targets of Well and Breeam, an extensive pre-handover testing schedule was developed, which highlighted any snags for resolution prior to the official Well performance verification. In terms of air quality, the testing was undertaken as outlined in Table 1.

Table 1: Pre-handover testing schedule

	Testing schedule	Rationale
1	Upon completion of the first three floors	To highlight any exceedances on the air quality threshold and raise the need for immediate remediation
2	Pre- and post-furniture	To assess the impact furniture has on air quality
3	Pre- and post-flush-out	To assess the impact a flush-out has on air quality

Air quality testing results



Environmental sensing system for ongoing IEQ monitoring by occupants

Human-centric design does not end at handover, and the building has more than 600 sensors monitoring indoor environmental quality (IEQ) indicators, including CO_2, particulates and VOCs. While the FM team will be analysing this data to optimise the building, digital signage on each floor means employees can use the data about temperature, humidity and air quality to inform their seating choice.

Conclusions

A performance-based target is essential to get the design team engaged with indoor air quality from an early stage of the project. A summary of the conclusions is outlined in the points below:

- With a focus on internal finishes and furniture, low levels of tVOC and formaldehyde can be achieved. However, introduction of furniture generally increased the overall tVOC levels.
- To achieve the above, extensive engagement with the whole project team is required.
- As expected, levels of PM2.5 and PM10 were elevated when any level of construction work was being undertaken.
- It is possible to achieve the particulate levels required by Well, via a combination of good practice construction methods and an extended flush-out, in addition to the use of compliant materials and furniture.
- Pre-completion testing is highly recommended.
- Once the building is operational, it is important that the facilities management team is briefed in terms of additional maintenance requirements, to maintain good levels of IAQ. This involves additional engagement with an FM team, which may not usually occur.
- IAQ should be more thoroughly assessed when it comes to designing reception areas. Next steps for the research would be analysing the operational data to determine the longer-term impacts of the measures undertaken during design and construction, and the on-going impacts and optimisation through operation. **CJ**

References:

1 Well Building Standard (v1).
2 *City of London Air Quality Annual Status Report for 2017*, 31 May 2018.

SAM CARLSSON is a senior sustainability consultant at Hoare Lea

Research suggests succulents such as *Zamioculcas zamiifolia* could be effectively used in indoor green walls

Plants as a building service

Plants are proven to remove pollutants and improve air quality, but which species should be considered? Researchers from the University of Birmingham and the RHS review the latest research looking for answers

Plants feature in many ways within indoor environments – from simple houseplants to complex, species-rich green walls – and they offer multifaceted services, including pollutant removal and reduction of building energy consumption.

This review identifies pollutants that have been measured at harmful concentrations indoors and gives health assessments of each. It explains which plants remove '2019's priority pollutants' effectively and directs research to those that have not been investigated. Finally, it consolidates the current research, presenting why plants should be considered a building service.

Plants deliver an array of benefits indoors, offering improvements in human health (pollutant removal) and in building energy consumption by the removal of carbon dioxide (CO_2) and relative humidity (RH) regulation – which, in turn, reduces ventilation requirements.

Numerous airborne pollutants are present in indoor environments: these include volatile organic compounds (VOCs), inorganic gases/vapours (CO_2, nitrogen dioxide – NO_2) and particulate matter (PM). The main sources of such pollutants are indoor human activities, construction materials, and the infiltration of outdoor-produced particles and pollutants.

Activities such as cooking, cleaning and painting produce numerous indoor pollutants. In addition, the closure of windows – and a push for more tightly sealed buildings in an attempt to reduce energy consumption – leads to an accumulation of indoor pollutants.

Indoor pollutants vary in toxicity and prevalence. Prolonged exposure to an indoor pollutant, at a concentration greater than the recommended guideline, can cause symptoms such as mild sensory irritation (in the presence of alpha-pinene, for example) to significant respiratory problems (NO_2) and cancer (benzene).

Indoor plants have been shown to remove a wide variety of organic and inorganic pollutants, PM and ozone. Houseplants can also help alleviate the symptoms of sick building syndrome (SBS).

High indoor concentrations of CO_2 are harmful to human health, increase absenteeism and reduce cognitive performance, so HVAC systems are designed to keep concentrations low, with ventilation increasing energy consumption. Indoor plants can act as a simple, low-cost ventilation surrogate, contributing to CO_2 removal indoors and reducing the requirement for traditional HVAC systems by about 6%.

Indoor plants can also reduce energy consumption by increasing RH. HVAC systems typically attempt to keep RH in the range of 40-60% – where the majority of adverse health effects can be avoided. A RH that is either too high (> 60%) or too low (< 40%) can cause health and building issues. High RH » encourages fungal and mould growth, and contributes to the deterioration of building materials. Low RH can cause dryness of the eyes, skin and mucus membrane, enhance indoor ozone, increase the likelihood of influenza transmission, and exacerbate problems of static electricity.

Our review aims to improve the current understanding of which indoor pollutants – and at what concentrations – are harmful to health.

A systematic review of the literature was conducted to determine the indoor pollutants measured in home environments, up to and including 2018.

Logue *et al* compared indoor pollutant concentrations with relevant health guidelines produced by the Environmental Protection Agency (EPA) and California Office of Environmental Health Hazard Assessment (OEHHA) for 67 home environments between 1998 and 2010. They identified nine 'priority' indoor pollutants (see Figure 1, which does not include butadiene) considered to be harmful. All were chosen on the basis of the measured concentration data exceeding health guidelines and the number of homes affected.

Since 2010, an assessment of 'Logue's priority pollutants' and their mean concentrations in indoor environments has not been carried out. So we have used data from home environments after 2011 to determine if concentrations of these nine pollutants have changed since.

Furthermore, we compare the post-2011 results with up-to-date chronic health guidelines produced by the World Health Organization (WHO) and US EPA (Figure 1). Any pollutants with an average long-term concentration greater than the appropriate guideline will be designated a '2019 priority pollutant'.

The data collected in Figure 1 suggests that the mean concentrations of four indoor pollutants have increased in studies after 2010 – namely, benzene, naphthalene, NO_2 and PM2.5. Reductions in concentrations of acetaldehyde, acrolein, dichlorobenzene – 1,4 and formaldehyde were measured, perhaps because of a large body of research focusing on lowering pollutant emissions from building materials.

Acetaldehyde, benzene, formaldehyde, and NO_2 are the indoor pollutants commonly measured at concentrations greater than the appropriate guidelines (Figure 1) – causing long-term health issues and, thus, being classified as 2019's priority pollutants.

Up to 10 *Dracaena fragrans* could be used in a green wall without raising office RH above 60%

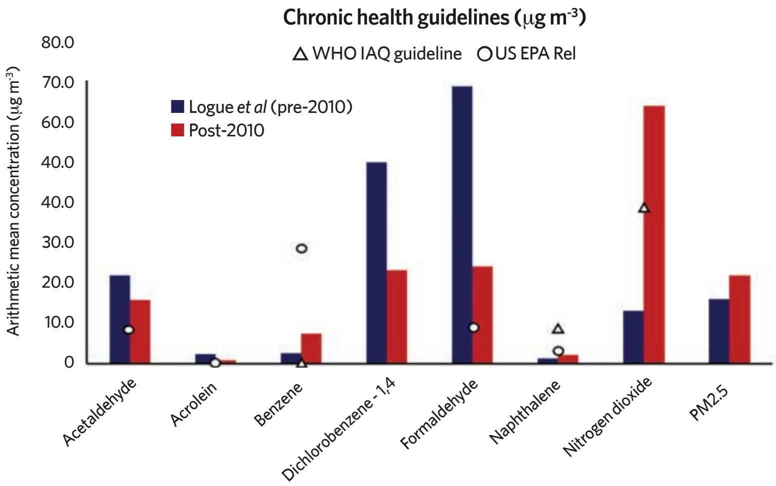


Figure 1: Arithmetic mean concentrations of 'Logue's priority pollutants', pre- and post-2010. Triangles and circles in the figure represent the appropriate chronic health guideline produced by the WHO and the US EPA. Butadiene has been omitted from the figure because no data was found post-2010 in home environments

Indoor plants

Forty studies have investigated numerous indoor plants for their ability to remove the '2019 priority pollutants' benzene (> 45 species/cultivars) and formaldehyde (> 150 species/cultivars). The results from the most robust, well-cited and informative studies from these have been selected and are presented in Table 2.

To the author's knowledge, no studies have investigated the potential of indoor plants to sequester either acetaldehyde or NO_2 – although the removal of NO_2 by outdoor plants has been thoroughly studied, with promising results.

Plants as a building service

CO_2 removal

The main sources of CO_2 indoors are human respiratory emissions and the outdoor air-supply rate. Several health guidelines exist for maximum safe CO_2 concentrations, with the lowest eight-hour guideline being recommended by ASHRAE, at 1,000ppm.

2019's priority pollutant	Indoor sources	Main health concerns from exposure
Acetaldehyde	Deodorants, foods and alcoholic drinks	Carcinogen, and an irritant to eyes and airways
Benzene	Building materials, furniture, heating and cooking systems, cleaning, painting and consumer-product use	Blood dyscrasias and leukaemia, lung cancer, all haematological cancers and multiple myeloma
Formaldehyde	Building materials, furniture, consumer-product use and combustion processes (for example, heating, cooking and smoking)	Myeloid leukaemia and airway cancers
NO_2	Combustion processes (heating appliances, fireplaces and stoves)	Respiratory illnesses, airway inflammation and decreases in immune defence

Table 1: The indoor sources and health issues associated with 2019's priority pollutants

A number of studies have focused on indoor plants and their ability to reduce CO_2 concentrations, with several focusing on houseplants specifically. Studies vary in scale and focus, but most use experimental chambers enclosing a single or small number of houseplant species.

Studies generally find that significant reductions can occur with the correct environmental conditions: namely, the light level. We found that raising the light level to 22,000lux – made achievable with supplementary LED lighting – increased the CO_2 removal 50-fold in some species.

Moreover, we estimated that 15 *spathiphyllum wallisii verdi* – a number that could, realistically, be installed in a small green wall – could offset 10% of a human's respiratory contribution. A similar study by Torpy *et al* found that a 5m² green wall containing *chlorophytum comosum* could balance the respiratory emissions of a full-time occupant using a similar lighting level.

RH regulation

Along with high CO_2 concentrations in indoor environments, an additional challenge is extreme RH (low < 40% and high > 60%). Both can cause previously described issues, mainly concerning human and building health. Several studies have investigated the effect of indoor plants on RH, with mixed results. Indoor plants have been shown to increase, decrease and have no statistically significant effect on RH indoors. Houseplants release water vapour into an environment through transpiration and would be expected to increase RH indoors.

Plant-species choice and ventilation rate would both significantly influence results, and most likely explain the mixed results in literature. However, correct employment of indoor plants, with species consideration, could help reduce the energy consumption of HVAC systems.

Our research suggests that less physiologically active plants – such as Guzmania sp, *dracaena fragrans* and succulents such as *zamioculcas zamiifolia* – could be used in larger numbers (10+), as part of indoor living walls within even smaller offices, without a risk of raising office RH above 60%.

Conversely, *hedera helix* (ivy) and *spathiphyllum* (peace lily) would be suitable in smaller numbers (five or fewer), or in larger rooms with greater overall volume, where their RH-influencing effect would be diluted.

Fifteen peace lilies in a green wall could offset 10% of a human's respiratory contribution

Conclusions

A significant body of research has looked at the ability of plants to remove indoor pollutants such as VOCs. Most, however, focus on pollutants that are detected infrequently indoors or at concentrations too low to damage human health. Experiments also commonly test pollutant concentrations that are not measured in real life (in situ).

This review highlights the range of concentrations present in situ and which indoor pollutants can be considered unsafe, to help direct future research.

Experiments suggest that the growing substrate, and the microorganisms within, are predominately involved in the removal of pollutants; plants themselves are only used indirectly to maintain and support substrate microorganisms.

Results generally suggest that the plant-substrate system can remove a wide variety of pollutants, but – with a lack of testing at in situ concentrations – extrapolation of the results to room level lacks accuracy. Further experiments should focus on the untested 2019 priority pollutants identified in this review, acetaldehyde and NO_2 – preferably at in situ concentrations.

Certain houseplants can remove CO_2 at significant quantities that would affect room-level concentrations, but only with the correct environmental conditions – for example, light level. Studies often suggest that a greater number of potted plants than would be feasible indoors are required to measure concentration reductions, so the density provided by green walls would be more suitable.

Studies are now beginning to investigate green walls and, additionally, how the »

Nephrolepis exaltata bostoniensis **or Boston Fern removed the most PM2.5 of plants studied**

substrate may influence removal – as measured with VOCs. RH literature has produced conflicting results.

Anecdotally, plants would be expected to increase RH indoors, but this is not always the case. We suggest a 'standard' method be devised – controlling chamber/room size and ventilation rate – to facilitate effective comparison between different plant species.

We believe plants should not be considered as a single entity, expected to provide all the above described benefits. There is large performance variability between species, so we recommend consulting literature to ascertain their suitability for a given benefit.

Although some benefits of indoor plants are less clear, when considered as a whole – with all the benefits combined – we believe plants should be considered as a building service, alongside traditional ventilation systems.

For a full list of references, see this article at **www.cibsejournal.com** or read the full paper at **www.cibse.org.uk/symposium** **CJ**

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Priority pollutant	Plant species tested	Result
Benzene	*Dracaena marginata* *Dracaena 'Janet Craig'* *Epipremnum aureum* *Howea forsteriana* *Schefflera 'Amate'* *Spathiphyllum 'Petite'* *Spathiphyllum 'Sensation'*	The authors found varying removal rates, from 12ppm d^{-1} (*Howea forsteriana*) to 27ppm d^{-1} (*Dracaena 'Janet Craig'*) – 40-88mg m^{-3} d^{-1}. These rates were maintained in the dark, rose linearly with a concentration increase, but could mostly be contributed to the growing substrate and not the plant.
Benzene	*Syngonium podophyllum*	The study compared plants grown in traditional substrate and hydroculture (no growing substrate) and concluded that indoor plants potted in traditional substrate (1,444 $\mu g\ m^{-3}$, rate for 50% benzene removal) possessed a higher removal rate than hydroculture potted plants (739 $\mu g\ m^{-3}$, rate for 50% benzene removal) – but both treatments removed significant amounts of benzene.
Formaldehyde	*Fatsia japonica* *Ficus benjamina*	Comparison of the above-ground plant parts and the root zone to remove formaldehyde in the day and night. *Fatsia japonica* removed formaldehyde faster than *ficus benjamina* (50% decay in 96 and 123 minutes respectively). Both plants removed formaldehyde in a 1:1 ratio (above-ground parts: root zone) in the day, and 1:11 at night. The root zone was found to remove formaldehyde primarily through the microorganisms and roots (90%) and a small amount through growing medium absorption (10%).
Formaldehyde	*Chlorphytum comosum* *Aloe vera* *Epipremnum aureum*	All plant-substrate systems removed formaldehyde, with *chlorphytum comosum* the most effective.The authors also determined that microorganisms in the substrate accounted for approximately 50% of the formaldehyde removal in all the plant-substrate systems.
$PM_{2.5}$	*Chlorophytum orchidastrum* *Ficus lyrata* *Nematanthus glabra* *Nephrolepis cordifolia* *duffii Nephrolepis exaltata* *bostoniensis* *Schefflera amate* *Schefflera arboricola*	Investigated the single pass removal efficiency (SPRE) of plants in an active green wall for PM2.5 removal. The authors found that all studied plants removed PM, with fern species recording the highest efficiencies. Nephrolepis exaltata bostoniensis removed the most PM2.5 with a SPRE of > 70%.

Table 2: Selected studies showing plants removing '2019's priority pollutants' benzene and formaldehyde

"Raising the light level to 22,000lux – made achievable with supplementary LED lighting – increased the CO_2 removal 50-fold in some species"

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Core fitness

As well as being the tallest building in the City of London, 22 Bishopsgate is the first major UK project to pursue Well Core and Shell Certification. Andy Pearson speaks to building services engineer WSP about the challenge of aiming high

Twentytwo, located at 22 Bishopsgate in the City of London, is billed as a new type of skyscraper – a vertical village accommodating office and social spaces, including a wellness centre, spa, yoga suite, gym, climbing wall, a dentist, restaurants and retail space. It is also the first major UK building to pursue Well Core and Shell Certification (individual tenants can decide whether they want to pursue Well Certification on their individual floors).

When it opens in October, the 62-storey tower, developed by Lipton Rogers Developments with AXA Investment Managers, will house up to 13,000 'villagers' in 118,000m^2 of office space.

Construction of the giant concrete core is complete and work at the top of the tower is now focused on finishing the final sections of its steel frame, which will support the roof-top plantrooms, a public viewing gallery and several restaurants. At the foot of the tower, the first of the office floors, Level 6, is complete and fit-out teams are now racing up the building.

Being the first major project to aim for Well Core and Shell Certification was not without its challenges. 'Since we started work on achieving Well, the document has been revised, so our experience may no longer be valid,' says Richard Brailsford, project mechanical lead engineer at WSP, the project's building services engineer.

With the exception of the upper levels, all office floors have a 3-metre floor-to-ceiling height, and the building's perimeter is formed of full-height glazing to maximise views out. This consists of low-iron glass to let in more daylight.

According to Peter Rogers, from Lipton Rogers Developments: 'We've pushed the wellness aspect of this scheme; we're trying to get as much daylight as we can into the building, so we didn't want solar-tinted glass, which turns everything grey.'

All 50 office floors will be to Cat A standard; essentially, the mechanical and electrical services and suspended ceiling will be installed. It's a herculean task that involves the installation of more than 3,000, four-pipe fan coil units (FCUs) before the tower's expected completion at the end of the year. Fresh air for the offices is ducted via constant-volume boxes to the back of the FCUs.

Well Certification is predicated on US or ISO standards. 'We'd designed the ventilation rate to CIBSE codes and British Council for Offices [BCO] recommendation of 1.5L·s^{-1} per m^2 of floor, which was not recognised by Well, so proving compliance involved an annoying amount of additional work,' says Brailsford.

Another challenge was in designing the control system to ensure the temperature in the offices conformed to Well criteria. To meet BCO comfort conditions, the offices are cooled to 22°C +/-2°C. 'Well says that is too cold in the middle of summer and that the space is over-cooled. To comply with Well, office temperatures have to

The tower's steel frame is currently being wrapped around its huge concrete core

be at 24.5°C +/-1.5°C, so office temperatures can go up to 26°C,' Brailsford explains.

The solution was to fit a control system that, in the morning and afternoon, has to decide whether it is summer or winter. Depending on the season, the dead band will change.

'We've sized all the plant to BCO so it can do the bigger loads, but the control system ensures that those occupants that want to be Well-compliant can be.'

There was a different Well compliance challenge in winter because the building is so well insulated, which means it is cooling most of the time. 'If it's 10°C outside, we're probably cooling,' says Brailsford.

If a space is being cooled, Well requires the temperature to

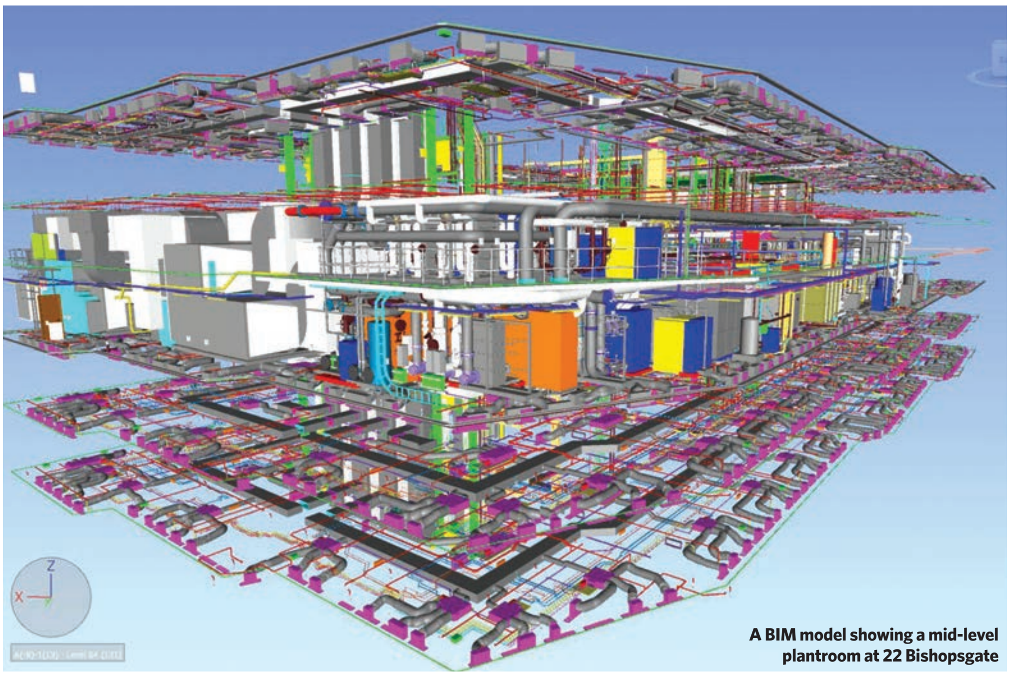
> "We've pushed the wellness aspect of this scheme; we're trying to get as much daylight as we can into the building"

increase, but increasing the temperature in winter to 26°C would make the space too warm. 'It's not that we are heating too much, it is that we are not cooling enough,' he adds.

'We have to have a control system that is constantly looking outside and moving its conditions to maintain the temperature differential. On a Class A office city building, it is unusual to adjust the temperatures up and down depending on what's happening outside.'

Brailsford adds that the most noticeable impact of Well is on the staircase lighting. 'We tend to assume staircases are back of house, but – in Well – they are classed as front of house, and you are encouraged to make them light and jolly,' he says. 'The stairs are now lit to a minimum of 250lux, whereas we'd have probably gone with about 150lux.'

Read a future *CIBSE Journal* for a detailed description of the tower's building services strategy. **CJ**



A BIM model showing a mid-level plantroom at 22 Bishopsgate

Evaluating dynamic lighting

Dynamic 'circadian' lighting varies in colour and intensity during the day, but does it improve alertness and help people sleep? BRE's Paul Littlefair and Cosmin Ticleanu describe an experiment that aims to find out

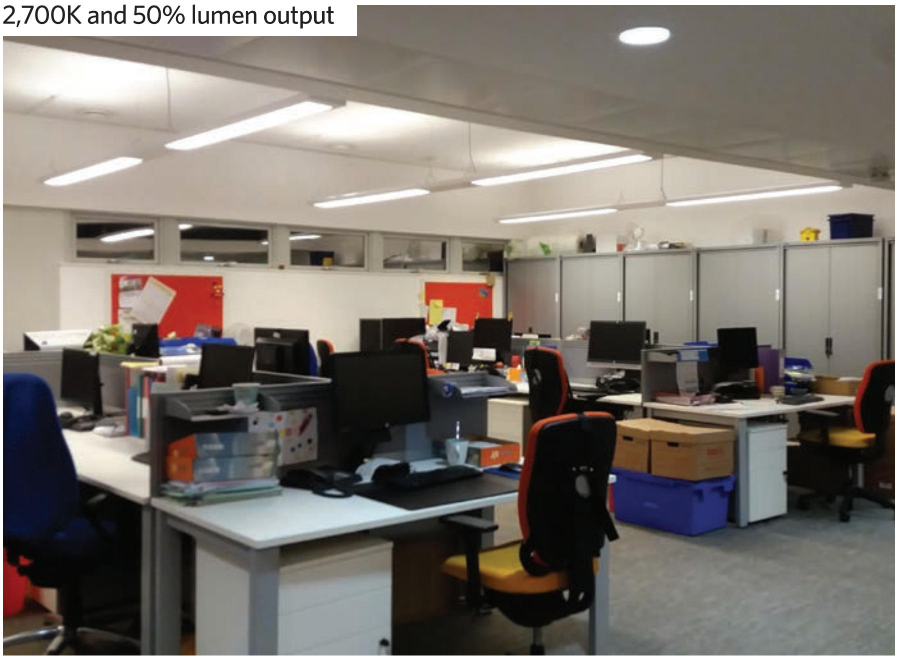
Circadian rhythms control our alertness and sleep, and the release of hormones. Daytime exposure to light, especially blue light, helps synchronise the circadian clock, enabling us to feel alert during the day and sleepy at night. Many people work in poorly daylit spaces, however, with relatively low levels of electric light, and it may be hard for their bodies to maintain their circadian rhythms.

Dynamic 'circadian' lighting is being marketed using dimmable, colour-changing LEDs to give brighter, bluer light in the middle of the day, and dimmer light – with less blue – later in the day when it is time to relax. BRE carried out an experiment – funded by the BRE Trust and CIBSE Research Fund – to investigate the effects of dynamic lighting and its timing on human subjective assessments, activity and reported sleep.

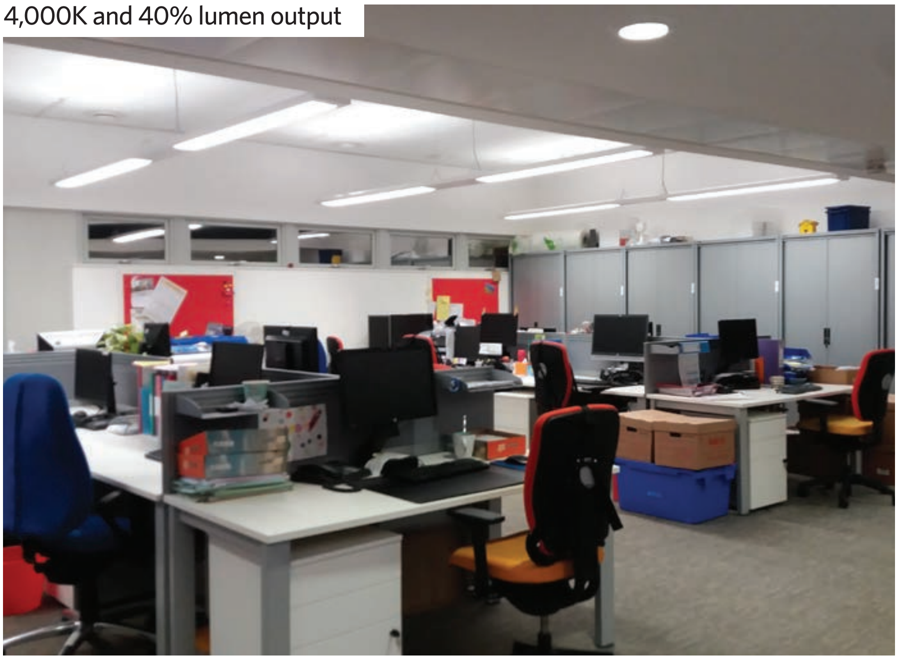
Figure 1: Office space with the original fluorescent lighting

Figure 2: Office space lit by the new LED lighting at different settings

2,700K and 50% lumen output



4,000K and 40% lumen output

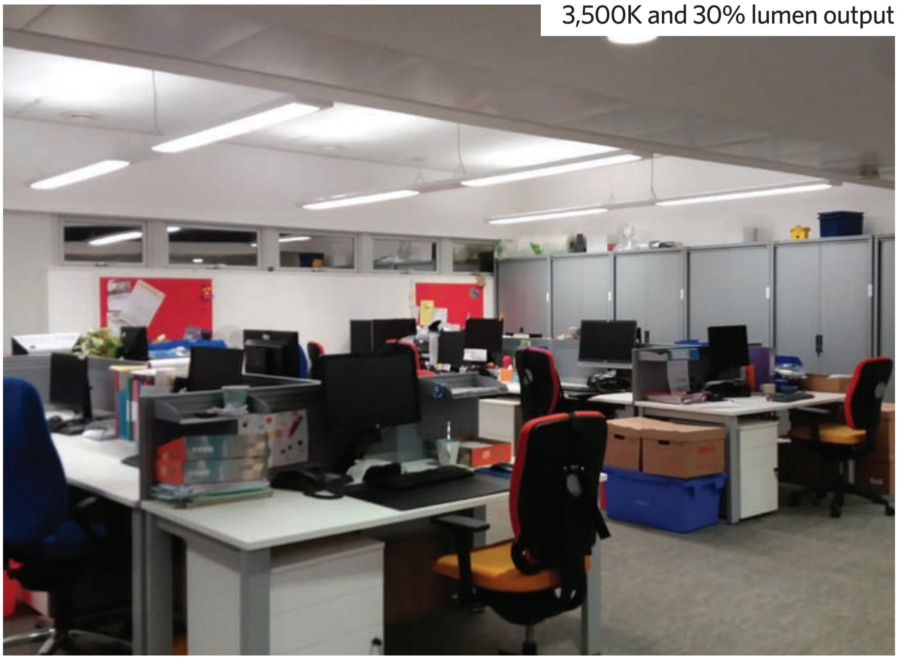


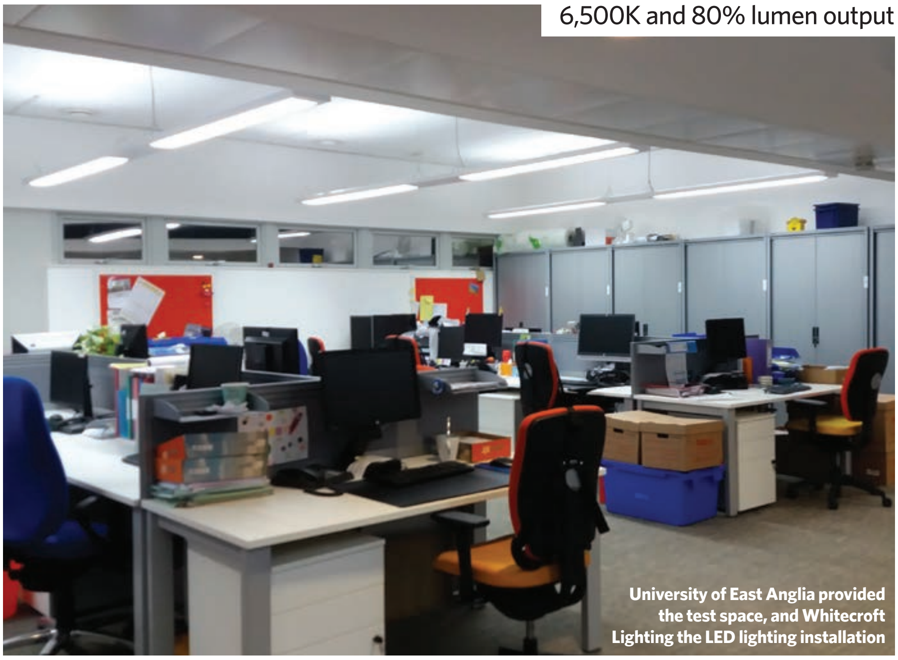
The experiment

The experiment took place in an open-plan office in Norwich, UK. There was very little daylight, and the windows were small and heavily obstructed by overhangs and nearby buildings. Of the 36 people who worked in the space, 23 (19 women and four men) opted into the experiment. Initially, in

February 2018, the space had constant fluorescent lighting (Figure 1, Condition 1). Most of the lighting was 4,000K (white), but some luminaires had 3,000K (warm white) replacement lamps. Some of the tubes had been removed when the occupants complained that the lighting was too bright, so the lighting was non-uniform. The mean horizontal illuminance was 377lux – in line with the 300lux recommendation for computer users in offices – but desk illuminances ranged from 129lux to 1,017lux.

After two weeks of monitoring the existing lighting, it was replaced with LEDs at the start of March 2018. For the first week, the new lighting was maintained at constant light output and colour, to allow participants to adapt to its appearance. The LED lighting was then programmed to change dynamically (Figure 2), and there was a further two weeks of monitoring. Figure 3 shows how the LED lighting changed with time of day. In the early morning, it became brighter and bluer until, at 10:30, it was at its coolest setting (6,500K colour temperature). From 12:30 onwards, the colour started to change again to become a standard white from 14:00. At 16:00, it started to become dimmer and redder, with 2,700K colour (similar to domestic lighting) by 18:30. The y-axis is scaled in a quantity called equivalent melanopic lux (EML).


3,500K and 30% lumen output


6,500K and 80% lumen output

University of East Anglia provided the test space, and Whitecroft Lighting the LED lighting installation

This measures the light entering people's eyes, weighted by the spectral response of the special cells in the retina (ipRGCs) that influence circadian rhythms. These cells are particularly sensitive to blue light. For comparison, the fluorescent lighting had a mean EML of 101, though this varied a lot over the space. The Well Building Standard v2 recommends at least 150 EML in a non-daylit space and, for maximum credits, 240.

Most of the variation in EML over the day was because of the change in colour of the LED lighting. Visual illuminances did not vary as much, with mean horizontal illuminances ranging from just over 350lux at the start and end of the day, to 488lux in late morning. The aim was to give an appropriate level of light to work by at all times.

Additional variable lighting conditions were administered in the second phase of the project, in November and December 2018, when 20 participants took part. For the first two weeks of monitoring (Condition 3), the LED lighting was programmed to change dynamically (see Figure 4) in a different way, with higher EML values. Mean horizontal illuminances varied from around 600lux at the start of the day to 1,120lux in late morning and 670lux at the end of the day.

Once the monitoring for Condition 3 was over, the LED lighting was set (Condition 4) to a constant light output and colour (4,000K) to replicate typical office lighting (mean horizontal illuminance 480lux, mean EML 149), and monitored for two weeks.

Results

Participants gave subjective assessments of the space after each condition, and responses in the morning and afternoon, on two days a week, to assess their subjective alertness, reaction time and concentration.

With the new dynamic LED system (Condition 2), average scores for subjective alertness – in the afternoon and across the day – were significantly better than with the old, constant fluorescent lighting (Condition 1). However, no statistically significant differences were found in the average scores for subjective alertness between dynamic (Condition 3) and constant (Condition 4) LED lighting. There were also no statistically significant correlations between increases in circadian-weighted lighting (more EML) and variations in subjective alertness between the two conditions tested in each phase of the project.

Figure 5a and 5b show the results. Most people felt more alert under the dynamic LED lighting in Condition 2 compared with the constant fluorescent lighting »

Variation in average EML for the LED lighting with time of day

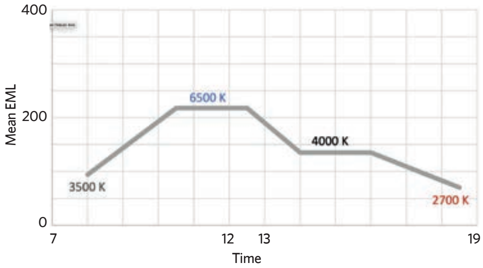


Figure 3: Condition 2, March 2018

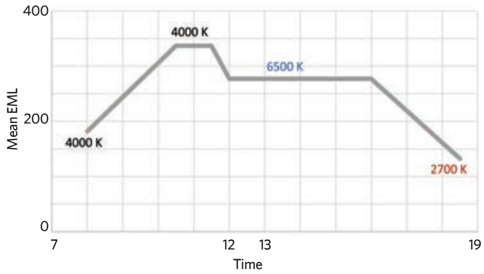


Figure 4: Condition 3, November 2018

Absolute difference in subjective alertness scores plotted against the relative difference in EML

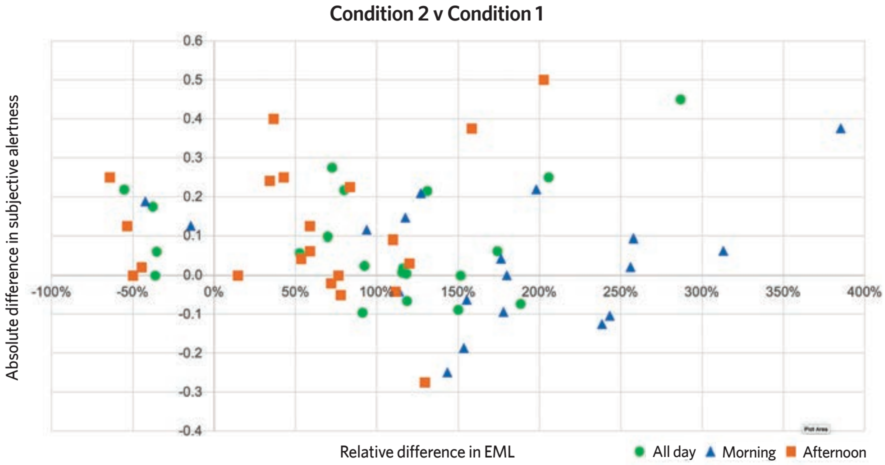


Figure 5a: Condition 2 (the first dynamic LED lighting condition) v Condition 1 (the original fluorescent lighting)

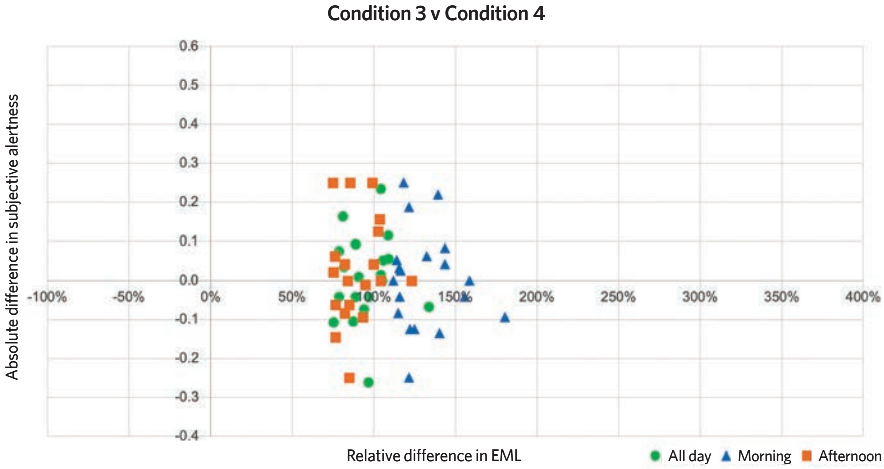


Figure 5b: Condition 3 (the second dynamic LED lighting condition) v Condition 4 (constant LED lighting)

» in Condition 1, but this also happened for the small number of people who received less light in Condition 2. The increase in alertness did not depend significantly on how much extra light people had with the LEDs. All participants received more light in Condition 3 compared with Condition 4, and the increase in light level was much more uniform across participants, compared with the first conditions. However, the higher light levels in Condition 3 did not lead to higher scores for subjective alertness; only half of the participants felt more alert under the dynamic LED lighting (Condition 3).

Participants also did computer tests to assess their reaction time and concentration. There were no statistically significant differences in either between the two conditions tested in each phase of the project. Around half of the participants wore an Actiwatch device to monitor their activity and sleep patterns; there were negligible differences in sleep under the first two conditions. On average, just more than half of the participants preferred dynamic lighting for their office, typically brighter in the morning and following the variation of natural light outdoors. Around one-third preferred the constant lighting.

Discussion

People felt more alert under the new lighting system, but there appeared to be no correlation with how much light they received or the way in which the system was operated. This contrasts with results from other studies, although these mainly used high illuminances or very blue light.

There could be various explanations for this. The experiment had a relatively small sample size. People vary in their reactions to light and to their normal exposure to light; 18 of the 23 initial participants took at least one break to go out of the building during the day, so they would have been exposed to daylight then. Nevertheless, there were some valuable findings:

Light levels vary across a space. The new LED lighting appeared more uniform and all the lamps were working, but there were still big differences in the amount of light reaching different people's eyes. Under the 6,500K (late morning) setting, EML values ranged from 142 to 413. In multi-occupant spaces with conventional ceiling lighting, it is very difficult to achieve a standard 'dose' of light for everyone. If people are facing the walls, or near a walkway, less light will reach their eyes than people with their backs to the wall facing a brightly lit space.

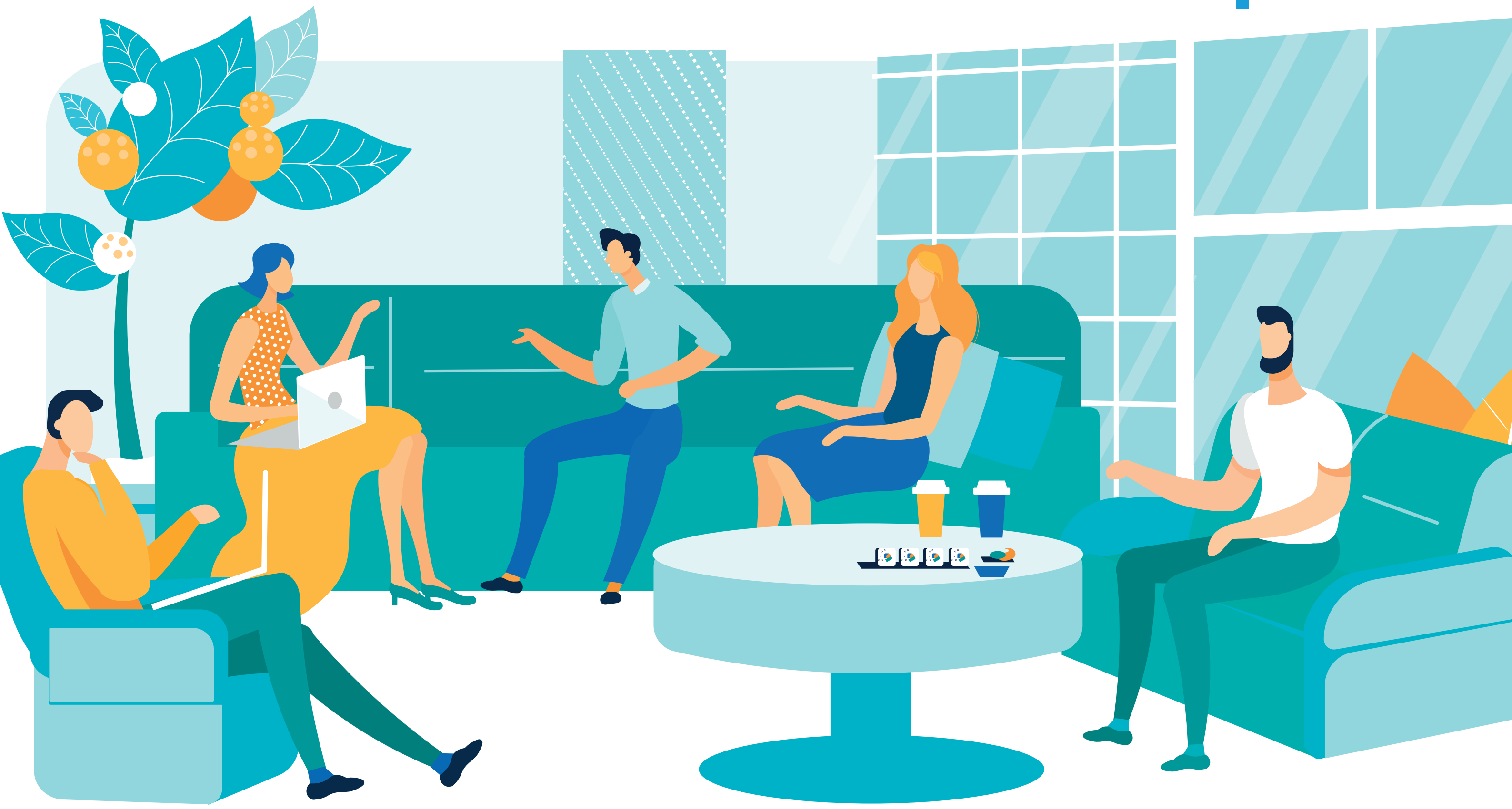
A balanced visual environment is important. For Conditions 1 and 2, the occupants had white desks and complained about light being reflected from them. To avoid unwanted glare in Conditions 3 and 4, they were replaced in the summer with desks in a light-oak finish, which allowed higher illuminances to be used.

Effective lighting control is critical. Dynamic lighting requires effective controls that work exactly as programmed. The dynamic lighting system used for BRE's study had reliable controls, and was programmed to vary slowly between settings.

Overall, the participants preferred the dynamic lighting, and elected to keep it at the end of the study. **CJ**

■ For references, see the online version of this article at **www.cibsejournal.com**

■ **DR PAUL LITTLEFAIR** and **DR COSMIN TICLEANU** are principal lighting consultants at BRE's Fire and Building Technology Group



Opening the debate

The need to improve the effectiveness of ventilation of buildings was the subject of the first event organised by the new CIBSE Health and Wellbeing Group. Phil Lattimore witnesses a healthy exchange of views on how to achieve good indoor air quality

Understanding how to design, implement and operate effective ventilation was the key theme at a recent debate hosted by the new CIBSE Health and Wellbeing Group.

The aim of the roundtable was to identify the issues that prevent adequate ventilation for building occupants, and to understand how industry practitioners can contribute to improved levels of design, installation and operation for ventilation systems.

Experts were drawn from across the industry and included representatives from engineering, architecture, academia, and government.

The participants explored areas that have an impact on ventilation, such as: site-planning considerations around noise and air quality; industry standards and building regulations; choice of either natural or mechanical ventilation strategies; the appropriate application of building simulation; and the design process. They pinpointed issues around commissioning, and concluded that there was a lack of post-occupancy feedback to inform future best practice.

PARTICIPANTS

Chair: Ashley Bateson, partner at Hoare Lea and chair of the CIBSE Health and Wellbeing Working Group
Ben Abel, head of research and development at engineering consultancy Hilson Moran
Henry Pelly, senior sustainability consultant at Max Fordham
Clare Murray, head of sustainability at Levitt Bernstein Architects
Malcolm Cook, professor of building performance analysis at Loughborough University
Dr Chris Iddon, chair of the CIBSE Natural Ventilation Group
Richard Daniels, manager of the technical and design team at the Department for Education
Darren Woolf, head of building physics at Hoare Lea, and chair of CIBSE Building Simulation Group
Julie Godefroy, technical manager at CIBSE

Ventilation effectiveness

'What is meant by "ventilation effectiveness"?' This question was raised as a starting point to a discussion about how designers need to focus on ventilation performance.

'The simple building physics definition is that ventilation effectiveness is about removing contaminants from the space. Increasingly, however – as we look at health and wellbeing – it's about supplying sufficient fresh air in the right place to meet the needs of the occupants. It's about more than just achieving a certain carbon dioxide level,' said Ashley Bateson.

He used the overheating phenomenon in schools and residences as an example. 'The ventilation could far exceed minimum ventilation regulations for hygiene but still not be "effective",' Bateson said. 'It has to be the right amount of air, of the right » quality to meet the functional needs of that space.'

The roundtable endorsed the view that there should be more focus on ventilation that meets the needs of the occupants, rather than a simplistic intention of ventilating a space – whether natural, mechanical or both. 'We really need to move away from talking about ventilating space to talking about ventilating for people,' said Julie Godefroy.

Systems thinking

The panel agreed that provision of ventilation required a systems approach. They concluded that an effective ventilation strategy should consider a range of factors, such as minimum fresh air requirements for hygiene, air quality, acoustics, safety, thermal comfort and avoiding draughts. External conditions may be noisy and polluted, for example, so the ventilation strategy needs to be considered in an integrated way, to mitigate these detrimental factors.

Considering various strategies, the roundtable discussed natural ventilation, and debated whether the 'rules of thumb' industry guidance that comes out of the BRE natural ventilation guide, and currently used by designers, was too simplistic and no longer relevant for modern applications.

The roundtable agreed a systems approach to ventilation was needed

Malcolm Cook, who gave a detailed presentation on ventilation efficiency, said: 'It's time we challenged these rules of thumb and put some science behind them – whether that be computational flow dynamics (CFD) modelling, real-world field testing or experimental work. We have to try to understand this fundamental question: how effective is the ventilation?'

Henry Pelly had experienced very limited understanding of how natural ventilation works in architects' training, and that 'these [trainee] architects didn't even know these rules of thumb to start with'.

He said improved rules of thumb should be developed to help architects get a better starting position in the design stage before the building service engineers come onboard.

This brought up another important issue for the roundtable – the need for engineers to seek early influence to review options and optimise the ventilation strategy. Participants said clients and architects appreciate early advice from engineers on the façade and ventilation strategy, because window design strategy can be crucial to the success of the natural ventilation strategy. In addition, the location and size of plant equipment can have an impact on planning for effective natural ventilation.

Ashley Bateson said awareness of best practice would help achieve successful integrated ventilation

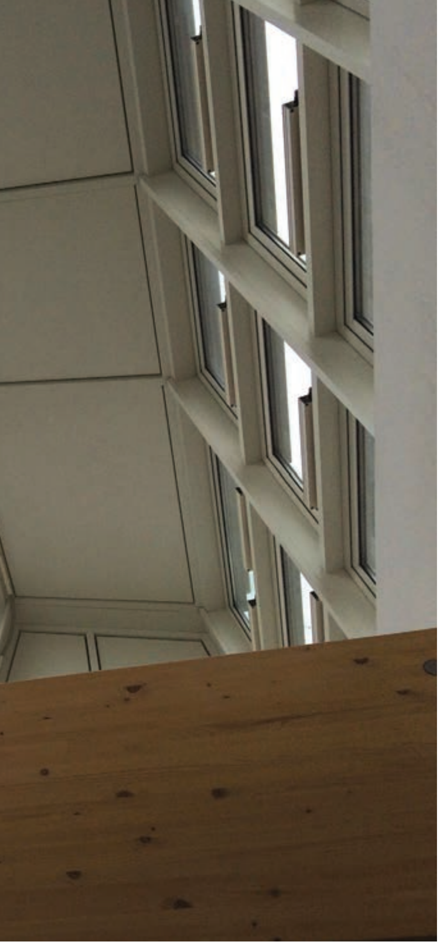
Clare Murray emphasised the importance of this early input. 'From an architect's point of view, there's a real desire to be having that conversation,' she said. 'There's some classic relationship behaviour between architects and engineers. Engineers feel like they daren't say something to the architects, but, in fact, architects are just wishing someone would say something early, to make it clear what will work and what's not compatible.

'There is some kind of barrier between architects and engineers, and it doesn't need to be there. It's partly to with language and partly to do with understanding what each other does.'

Pelly agreed. 'Definitely, education

POINTS FOR DEBATE

1. **Focus on ventilation performance: there should be more attention on ventilation that meets the needs of the occupants, rather than the simplistic intention of ventilating a space**
2. **Systems-thinking approach: an effective ventilation strategy needs to consider a range of factors, such as minimum fresh air requirements for hygiene, air quality, acoustics, safety, thermal comfort and avoiding draughts**
3. **Engineers should seek early influence to review options and optimise ventilation strategies**
4. **Testing and commissioning of ventilation controls is crucial**
5. **Post-occupancy evaluation will improve skills and raise awareness of effective ventilation performance.**



around communication needs to be developed in the industry to get through these issues.'

Richard Daniels suggested looking at the issues from a different angle. 'The only way I can think of bridging this disconnect is through case studies, with an engineer and an architect giving their different perspectives,' he said. 'If you think in the abstract, from just the engineer or the architect perspective, you will never bridge the gap.'

"If we could define metrics appropriate for healthy environments, we could force people to not just take the minimum route"

Testing and commissioning

The roundtable discussed issues surrounding the testing and commissioning of ventilation controls, and how vital this is in ensuring the intended design intent is implemented in practice.

Participants looked at case studies from educational buildings, where ventilation systems had failed or not met the requirements of the occupants because of issues with the control systems. In some cases, the lack of resilience built into solutions – such as the inability to open windows – had led to overheating.

They agreed that default control settings don't always meet the needs of occupants and appropriate adjustments are necessary. Systems can sometimes be overcomplicated or based on flawed assumptions about design flowrates and conditions; without full testing, these faults will be realised in operation.

The panel said that requirements for natural ventilation to meet Part F of the Building Regulations were often compromised by additional requirements under the regulations governing safety or noise.

'Quite often, buildings are sealed on the basis of an acoustic survey that is totally conservative in terms of assuming what would be acceptable for a teacher,' said Daniels. 'Most of the time, that might be completely right – but, in a heatwave for example, that level of tolerance may be different.'

He added that openable windows should always be an option and that buildings should be future-proofed for a potentially improved urban environment where, for example, electric vehicles may produce lower noise and improve air quality from current levels.

Evaluation and validation

The roundtable identified post-occupancy evaluation as a way to improve skills and raise awareness of effective ventilation. They agreed that engineers should seek opportunities to learn from the successful implementation – or otherwise – of ventilation systems after they have been handed over.

'The other thing we never consider is the validation afterwards,' said Ben Abel. 'It's only when you get an extreme case – where someone comes back because the building's overheating – that we ever find out what the problems are.

'If it's "sort of" working, then the residents often just put up with it, or they mitigate problems. We need some sort of post-occupancy validation so that we can establish what is working well and what needs to change.'

Darren Woolf suggested that defining appropriate metrics for evaluating effective ventilation was a way to create targets for designers and architects.

'If we could define metrics that are appropriate for healthy environments, we could force people to not just take the minimum route, which is happening at the moment, but actually do something that promotes lower air temperatures and higher air quality,' he said.

Woolf continued: 'We haven't yet grasped how to design well – and, partly, I think that is because we're thinking about it in silos. We haven't got that metric where you can define a healthy environment.

'An index could, for example, allow you to combine temperatures and concentrations; we could come up with an index where it is about a healthy environment – where a higher number shows you are doing better. It would be easy to communicate what we mean.'

Getting successful, integrated ventilation solutions is about increasing awareness of – and sharing – best practice, said Bateson.

'It's about raising knowledge.' he added. 'There's a need for a visual guide for good natural ventilation design that, in practice, will work and be effective, so that engineers and architects can see examples of what good – and bad – practice is, and adopt the best possible solutions.'

Murray stressed the need for straight talking and better communication of analysis, to ensure informed decision-making on effective ventilation strategies early in the process:

'Engineers need to be brutally honest with the architects when it comes to overheating analysis and not hide the results in order to show a pass,' she said..

'It's not going to help any of us if we're hiding from the reality and putting our heads in the sand.' CJ

Openable windows should always be an option, said Richard Daniels

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Lighting the way for occupant wellbeing

This module explores how the human eye processes light and the impact of artificial lighting on wellbeing

The significant role that the built environment can have in improving health, wellbeing, comfort and cognitive performance has prompted the current revision to the CIBSE Technical Memorandum 40 *Health Issues and Wellbeing in Building Services*. A key element of ensuring occupant wellbeing is to provide an appropriate visual environment. This article will consider the parameters sensed by the human eye and the impact of artificial lighting that contributes to the wellbeing of occupants.

The visual receptors in the human eye comprise of around 100 million rods and five million less sensitive, but faster response cones in the retina (as illustrated, in part, in Figure 1). The densely packed cones provide photopic vision for light at high intensities. **Mesopic** vision incorporates the range of light levels where signals from both rods and cones contribute to vision across a factor of 1,000 in luminance from the lower threshold of the cones up to the point where the rods are saturated with light (see Figure 2). This includes the levels that are often experienced in working environments, and where the spectral composition has a significant impact on the relative strengths of rod and cone signals. In dim light, **scotopic** vision takes over, integrating the light received by the rods as peak visual sensitivity shifts towards the blue end of the visible spectrum.

Vision for night activity is likely to be in the mesopic range, with the peak being somewhere between yellow-green and blue-green.[1] The intrinsically photo-sensitive retinal ganglion cells (ipRGCs) are located in the first layer of the retina but are not linked to vision. Alongside other inputs, the signals from the ipRGCs affect the master circadian clock – the part of the brain known as the suprachiasmatic nucleus – so influencing alertness and preparation for rest. The response of the ipRGC receptors, and therefore the impact of light on physiological processes, is strongly influenced by the spectral composition of light – their peak sensitivity is in the blue area of the light spectrum

Humans have evolved so as to be able to visually interpret objects and their surroundings at lighting levels ranging from in the order of 100,000 lux, in »

SEEING THE LIGHT

The candela, cd, measures the visual effect of optical radiation and is unique in being the only SI base unit that is related to human perception. Originally based on a 'standard candle' a candela is now defined by the luminous power emitted by radiation of frequency 540 x 10^{12} hertz (the green-yellow region of the spectrum, where human vision is most receptive) that has a radiant intensity of 1/683 watts per steradian, sr. (The surface area of a sphere with radius r is $4\pi r^2$, and so, as a sphere is 4πsr, the surface area of 1sr is r^2 or around 8% of a sphere's surface area.) For a particular lamp, the luminous intensity, measured in cd, will be dependent on the position of the viewer.

The lumen, lm (also cd·sr), is the luminous flux emitted within one steradian by a point source having a uniform luminous intensity of 1cd.

Although a lamp will have many position-dependent values of candela, it will have only one lumen output, which will depend on the type of source and spectrum of light and will be the sum of all measured values of individual values of (cd x sr) around the sphere.

Illuminance on a plane is represented by lux, lx (also lm·m^{-2}). So, for example, typically for task areas in offices, this would be either 300lux for mainly screen-based activity or 500lux for mainly paper-based work.[6]

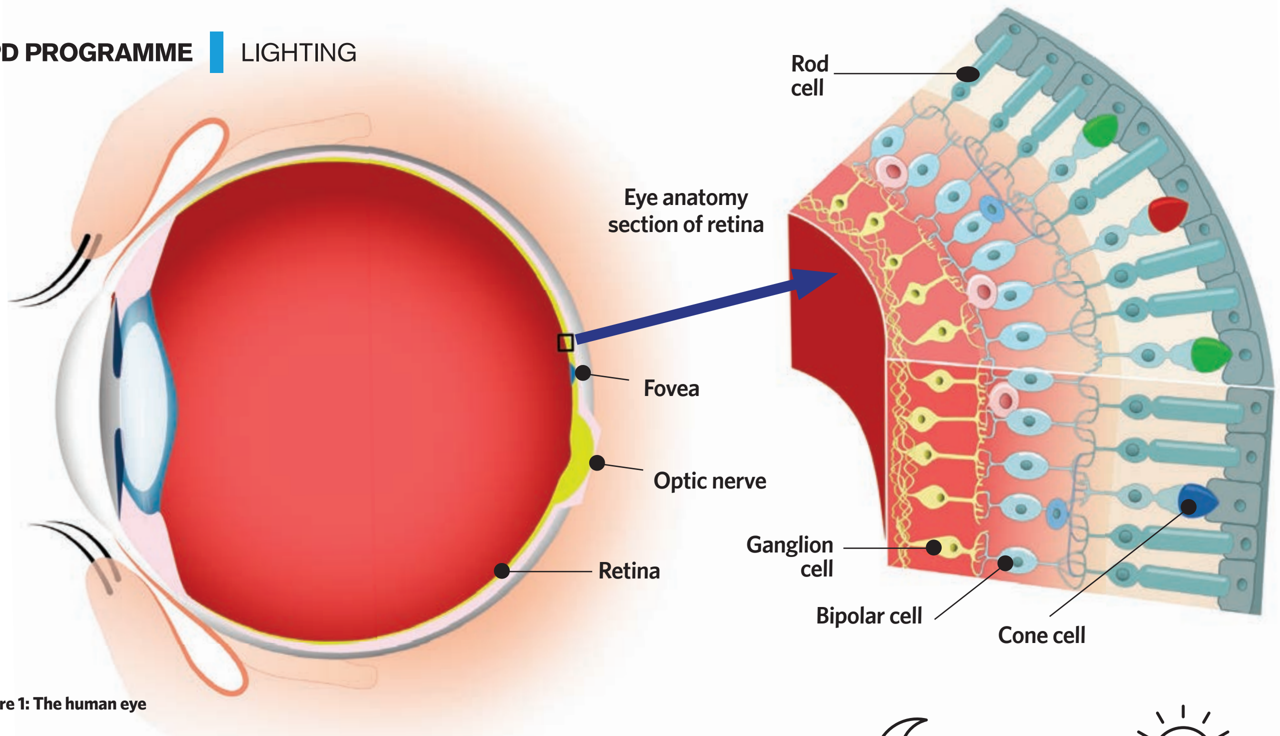

Figure 1: The human eye

extremely bright sunlight, to less than 0.01 lux on a (practically colourless) moonlit night (see boxout 'Seeing the light'). Despite being able to see at very low values of illuminance, the opportunity to undertake activities comfortably and safely requires a visual environment that should meet both the physical and psychological needs of a 'quality' visual environment. Negative visual impacts should be minimised, such as eyestrain and the effects of glare and flicker (see boxout 'Flicker and glare') that can cause discomfort and can affect health if sustained over long periods, for sensitive occupants or where safety is directly impacted.

Increasingly, the circadian rhythm of occupants is considered as part of the lighting design process. The circadian system is a fundamental part of life and can be found in virtually all plants and animals, including humans. This regulates a wide range of physiological and behavioural systems including digestion, metabolism, the release of hormones, the control of core body temperature and alertness/sleepiness.[2] Melatonin is the hormone that drives humans towards winding down and ultimately sleep. This hormone naturally increases throughout the afternoon and evening, from light to dark, and while it is a key hormone to regulate sleep-wake patterns, it is also linked to the regulation of digestive functions.

Cortisol is a hormone that is associated with adrenaline, which affects the state of readiness in a human. With a normal circadian rhythm, cortisol is secreted in the early morning dark to light period, helping the human body start the day. Warm white lighting temperature, with a correlated colour temperature of around 3,000K, stimulates melatonin production that, in turn, inhibits the production of cortisol, so reducing the state of readiness. Natural sunlight has a

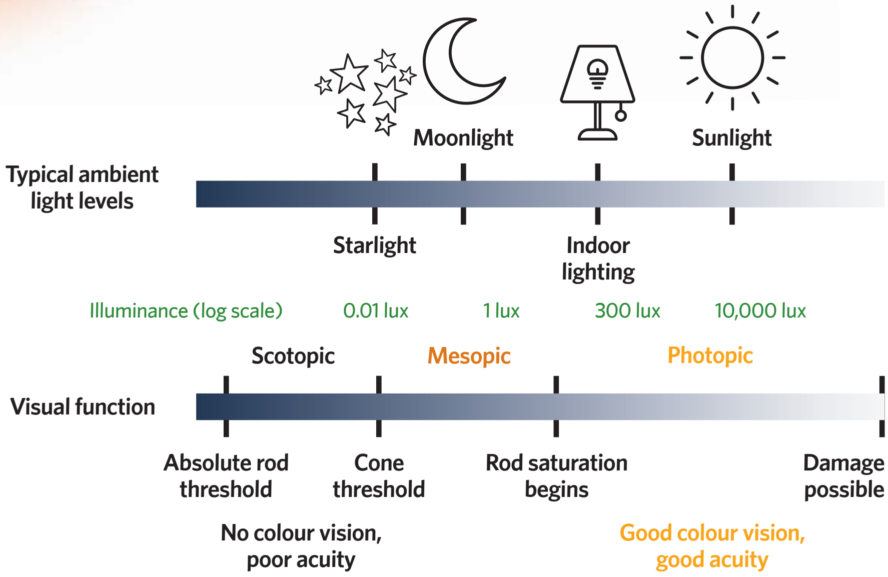

Figure 2: Scotopic, mesopic and photopic vision

cooler, bluer colour temperature as the morning progresses towards midday; it then reverts to a warmer white as the afternoon becomes evening. Studies[3] have shown that blue light reduces levels of melatonin and increases cortisol. When humans spent the majority of their time outside, being influenced by the sun and its natural movement throughout the day, cortisol and melatonin were automatically regulated, without disruption (as illustrated in Figure 3).

A large body of evidence suggests that daylight has a significant positive impact on health and wellbeing, linked to avoiding sleep disruption and allowing restorative sleep, and providing an environment that has a positive impact on mood, alertness and performance – as well as reducing the symptoms of depression. Conversely, inappropriately lit environments have been associated with sleep disruption, as melatonin levels are depressed, with consequent detrimental health consequences.

Artificial lighting for wellbeing

The unique and complex qualities of daylight are still not fully understood, but there is unanimity that, wherever practicable, daylighting should be maintained. There are

CORRELATED COLOUR TEMPERATURE

Correlated colour temperature (CCT) interprets the colour of light emitted by a lamp, relating it to a reference source when heated to a particular temperature, measured in Kelvin (K). Contrary to normal perceptions of temperature, lamps with a CCT below 3,300K are usually considered 'warm' and those above 5,300K are usually considered 'cool'.[7] (CCT is a simplification and provides no information on the detailed spectral output of the lamp.)

FLICKER AND GLARE

Glare may be caused directly by excessive luminance of light sources, both natural and artificial bright light sources, including small point sources such as LEDs. It can also be caused by the reflection of bright elements seen in the work environment, for example reflections on a computer screen. Disability glare impairs the vision of objects without necessarily causing discomfort; it can be produced directly or by reflection. Discomfort glare causes discomfort without necessarily impairing the vision of objects. Light sources should be protected from producing direct glare, for example by shielding of lamps and roof lights while at the same time preventing reflected glare, which is a particular problem with computer screens. Laptops and flexible workspaces can help, as users have more ability to modify where they sit and the orientation and angle of their screens.

Glare evaluation and prevention are discussed fully in the SLL Lighting Handbook.

Flicker (visible and invisible) can occur when the frequency of light output changes intensity rapidly. For example, when a power supply converts mains electricity from AC to DC, and the current is then sent to the LED, it can cause the light output to flicker because of high 'ripple' in the output current.[8] Ripple is caused by incomplete suppression of the alternating waveform after the AC power has been rectified, and typically will be at twice the frequency of the supplied power – in Europe this can cause a 100Hz flicker. 100Hz is above (and outside) the frequency range that has been associated with photosensitive epilepsy; however, in the frequency range of 100Hz to 200Hz, where the flicker is too rapid to be seen, it is still resolved by the human retina,[9] and so may influence occupant wellbeing. The depth of the flicker with LEDs is likely to be greater than for fluorescent lamps (as LEDs do not benefit from the phosphors that provide persistence) and since fluorescent lighting (controlled by magnetic ballast producing 100Hz flicker) has historically been linked with headaches, it is likely that the effect from LEDs could produce similar issues.[9]

Point sources of light, such as single LEDs in appliances, are less likely to induce health problems than a diffuse source of light that covers most of a person's field of vision, as would be used in general lighting. Invisible flicker may be more likely to cause problems when the visual task demands precise positioning of the eyes, such as when reading. LEDs require good quality drivers to avoid flicker problems when dimming or mixing.

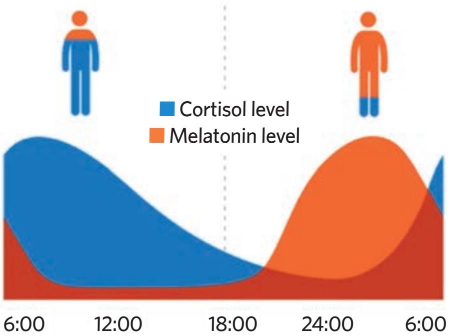

Figure 3: Simplified interpretation of levels of cortisol and melatonin in humans exposed to normal patterns of daylight (Source: Tamlite)

basic illuminance requirements to ensure the safety and wellbeing of occupants. Historically, illuminance on a horizontal plane has been specified; however, additionally, vertical illuminance (for walls and other surfaces) and cylindrical illuminance (to better interpret facial features) require proper consideration for more effective lighting of the internal environment to maintain wellbeing.

The benefits go beyond those of visual stimulation. For example, understanding speech is primarily an auditory task, but intelligibility is improved when the face of the speaker is clearly in view – especially when there is interference from background noise, when the speaker has an unfamiliar accent, or for people with hearing impairments. Reading fluency and concentration in the classroom have been shown[4] to be linked to lighting levels and colour temperature.

Electric lighting has a spectrum that lacks the complexity and is less evenly spread than that of daylight, and instead usually has peaks and troughs across the spectrum. However, LED luminaires can be tuned to a range of colour temperatures using a combination of individually coloured chips and, through connected lighting and DALI-enabled luminaires, are able to change the colour temperature throughout the day, mimicking the basic appearance of natural daylight, as illustrated in Figure 4.

Maintaining good colour rendering (discussed in the May *CIBSE Journal* CPD article) reportedly supports communication and sociability, and is important for the overall quality of the visual environment and the feeling of comfort and wellbeing. The aesthetic is so important that the European standard for lighting in workspaces, BS EN 12464-1,[5] recommends that the colours of objects and of human skin be rendered naturally, correctly and in a way that makes people look attractive and healthy.

Lighting products are evolving rapidly, with many seeking to replicate natural daylight cycles, promoting alertness and cognitive performance during the day and avoiding sleep disruption at night. They are also being used to adapt the internal environment to improve performance and wellbeing – so, for example, for those who are working late hours or night shifts, reducing melatonin levels could help prevent tiredness.

The scheduling of colour appearance, illuminance levels, directivity and texture is complex and includes the appreciation and understanding of psychology, aesthetics, and context including cultural preferences and the application. Any potential benefits should be carefully evaluated, as currently there is a paucity of robust standards covering 'lighting for health', while knowledge and understanding is still evolving.

- Part of the material in this article is abstracted from the extensive information that is contained in the various lighting guides that are produced by the CIBSE Society of Light and Lighting, as well as the work that is being developed for the upcoming CIBSE Technical Memorandum 40.
- Turn to page 28 for references.

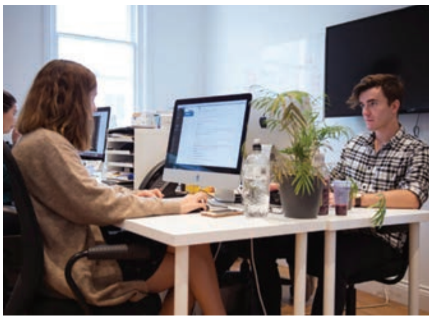

Figure 4: Adapting the lighting to meet the needs of the occupants' circadian rhythm – morning 4,000K; noon 5,500K; and afternoon 3,000K (Source: Tamlite)

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Module 147

June 2019

1. **What is the term used to describe the normal human vision that would prevail in an office application?**

- ☐ A Mesophilic
- ☐ B Mesopic
- ☐ C Mesoprosopic
- ☐ D Metopic
- ☐ E Myopic

2. **Which of these illuminances is likely to be most suitable for an office?**

- ☐ A 0.3 lux
- ☐ B 3 lux
- ☐ C 30 lux
- ☐ D 300 lux
- ☐ E 3,000 lux

3. **Which of the following times of day is a human naturally likely to have the highest level of melatonin?**

- ☐ A 9am
- ☐ B 12pm
- ☐ C 3pm
- ☐ D 6pm
- ☐ E 9pm

4. **What CCT is likely to be most beneficial for midday in an office to support a natural circadian rhythm?**

- ☐ A 5,500K
- ☐ B 4,000K
- ☐ C 3,000K
- ☐ D 2,500K
- ☐ E 1,000K

5. **Which CIBSE TM specifically considers aspects associated with wellbeing?**

- ☐ A TM25
- ☐ B TM30
- ☐ C TM35
- ☐ D TM40
- ☐ E TM45

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Further Reading:

SLL Lighting Handbook 2018 – provides detailed explanations of all lighting fundamentals SLL Lighting Guides 0 to 18 – these provide contextualised guidance on the design and application of lighting solutions

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1 Barbur, JL and Stockman, A, *Photopic, Mesopic and Scotopic Vision and Changes in Visual Performance*, Encyclopedia of the Eye, Vol 3. Oxford: Academic Press; 2010. pp. 323-331.

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3 Figueiro, MG and Rea, MS, *Lack of short-wavelength light during the school day delays dim light melatonin onset (DLMO) in middle school students*, Neuro Endocrinol Lett. 2010;31(1):92-6.

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5 BS EN 12464-1:2011 *Light and lighting. Lighting of work places. Indoor work places.*

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7 SLL Code to lighting, CIBSE.

8 **https://info.osram.us/blog/what-you-need-to-know-about-led-drivers** – accessed 5 May 2019.

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Demand-controlled ventilation for comfort, wellbeing and resource efficiency

This module looks at demand-controlled ventilation and the technology's potential application in providing energy-efficient solutions

Demand-controlled ventilation (DCV) is a strategy that is able to reduce building energy consumption while delivering good levels of occupant comfort. Most buildings regularly operate at occupancies below the design maximum, and can benefit from the ventilation being controlled to supply reduced flows that satisfy heating and cooling loads as well as meeting outdoor air requirements. This CPD will reflect on the state of current DCV systems and illustrate the potential application of the technology to a case study multi-use building.

The principles and controls that evolved to provide variable air volume (VAV) systems have been developed and refined to produce the modern DCV systems that not only control temperature (and humidity) but also optimise the supply air volumes – particularly outdoor air – so that appropriate levels of environmental quality ensure wellbeing while minimising energy costs. The resulting installations can provide significant energy savings (compared with constant air volume [CAV] systems) because of reduced fan power and reductions in heating and cooling of the ventilation air. Digital control, and increasingly wirelessly connected components, use distributed sensors and motorised air volume control dampers with linked optimising controllers to provide environments that account for the presence of occupants as well as meeting the individual zonal comfort requirements.

Many applications, including offices or schools, are almost never fully occupied, and it is unlikely that the peak design occupancy occurs simultaneously in those occupied rooms. Studies[1] have shown that, in cellular offices, typically fewer than 50%-65% of rooms in an office block are occupied concurrently and the 'normal' peak may only reach 75%-84% of all offices.

With a CAV system the airflow rate is kept constant, while with a DCV system it is modulated to meet the actual demand. The energy saving potential of a DCV system will depend on:

- The variation in, and periods of, occupancy and use of the rooms
- The minimum flowrate required and its relation to the design airflow rate of the system. This will depend, for example, on the number of rooms, the base ventilation rate in these rooms and the minimum airflow rate (the 'turndown') possible with the airflow control devices
- The chosen indicator for indoor air quality control. For example, if airflow rates are controlled by simple occupation (or building use) sensors, then the airflow rate in the room is likely to vary in just two steps: minimum and maximum, resulting

Figure 1: Engelsons retail store, offices, warehouse and dispatch area, Falkenberg, Sweden (Source: Engelsons, www.engelsons.se)

in higher overall airflow compared with alternative active measures of occupancy or building use, such as carbon dioxide (CO_2) or volatile organic compound (VOC) levels.

- The supply air conditions. The principal operational benefits of varying air volumes comes from the reduction in fan power required to move the air through the distribution network. This can be further enhanced by optimising the supply air condition so that the total energy use, including that used in any terminal devices (which may be able to heat and/or cool), is maintained at a minimum. This requires that the control and feedback from room devices, zone controllers and centralised plant are all linked, so that the integrating controller can optimise the supply air condition
- The availability of global intelligence. Where systems are connected with internet-based resources, this can feasibly include whole system control and supervision that is influenced by information provided by – for example – weather and environmental forecasts, energy tariffing, and cloud-based, manufacturer-linked, condition-based monitoring.

A case study investigation[2] was undertaken by Swegon and the University of Padua to investigate the potential operational benefit of applying DCV.

The Engelsons building located in Falkenberg, Sweden, constructed in 2009, was used as the basis of an investigation to determine whether there were potential total operational benefits from the adoption of DCV compared with a simple CAV system. The 2,200m^2, two-storey building was chosen for its mixed use, incorporating offices and retail with a packing area and a separate warehouse (which was outside of this study). The building was monitored, and a computer thermal model created and calibrated so that it provided a solid base for comparative system simulations. Unusually for such a building in Sweden, the building is not connected to district heating and is fully electric. Three sub-areas of the building – ground floor retail area (439m^2), ground floor packing area (514m^2) and first floor open-plan office (481m^2) – were monitored for more than two years. The air handling unit (AHU) control system provided recorded measurements of temperature, relative humidity, pressures and airflows, and distributed logging devices were used to monitor the temperature and humidity of various spaces. Over the period of data collection, the monitored flowrates were reasonably consistent (aside from a step-change in supply airflow rates following some unreported systems changes to the packing area and some periods where data was lost). The area was served by what was fundamentally used as a CAV system, but with the facility for local-boosted airflow, so effectively having the facility for VAV to increase the amount of air supplied – though this was not used during the monitoring period. Fortunately, the period of monitoring was sufficiently long that a full year's operational data could be extracted and linked up with the actual weather data for that same period. The investigating team selected weeks where the external temperatures were at the most extreme, to determine how well the systems controlled the spaces compared with the requirements of EN 15251,[3] as shown in Figure 2 for the 'summer' condition.

The comfort conditions were evaluated using long period comfort (LPC) – the cumulative hours over the period of each month that occupants have been outside of their comfort boundaries (as set by EN 15251).

The method that was employed is explained in annex F method C of EN 15251, which employs predicted percentage dissatisfied (PPD)-weighted time, where the time during which the actual predicted mean vote (PMV) exceeds the comfort boundaries is weighted with a factor that is a function of the PPD. The guidance[4] is that the PPD-weighted time of exceedance should not be greater than 150 hours per year.

Office zone: air temperature

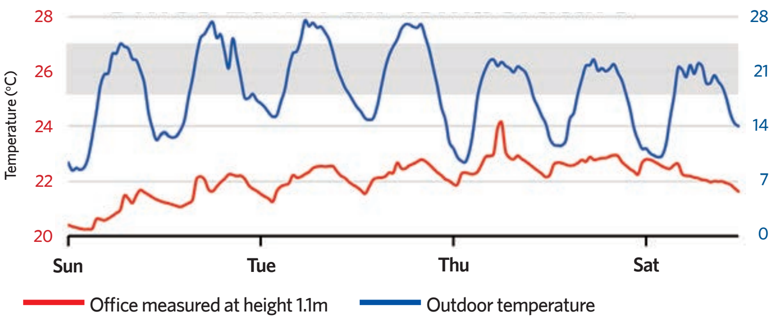
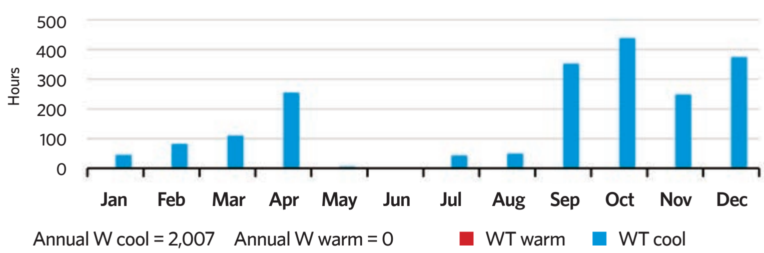


Figure 2: Internal and external temperatures over a week in summer conditions – shaded area is the recommended maximum temperature to EN 15251

Long period comfort

3a) Office zone: WT warm/cool



3b) Retail zone: WT warm/cool

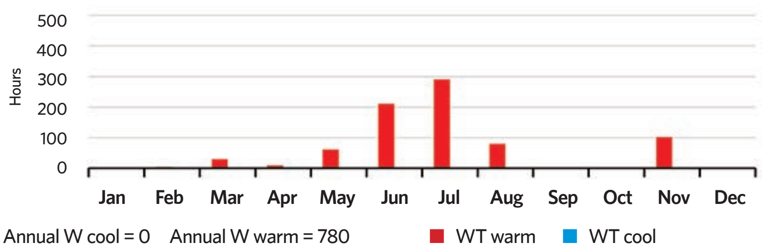


Figure 3: Monthly PPD-weighted comfort hours based on assumed level of activity and clo value synthesised from the running mean outdoor temperature – a) office area b) retail area

	Airflow (L·s⁻¹·m⁻²)		Minimum temperature (°C)		Maximum temperature (°C)	
	CAV	VAV min	Occupied	Unoccupied	Occupied	Unoccupied
Office	1.58	0.35	21.5	21.5	21.5	21.5
Retail	2.03	0.35	21.0	20.0	21.9	23.9
Packaging	0.95	0.35	20.6	20.1	22.1	24.1

Table 1: Set-points for CAV, VAV and DCV scenarios

	Minimum temperature (°C)		Maximum temperature (°C)	
	Occupied	Unoccupied	Occupied	Unoccupied
Office	22.0	20.0	24.5	26.5
Retail	19.0	17.0	23.0	25.0
Packaging	19.0	17.0	23.0	25.0

Table 2: Set-points for DCV 'class 1' scenario

However, considering the results of these evaluations (as shown in Figure 3 for the office and retail areas), the office has 2,007 PPD-weighted hours of being too cool and the retail area 780 PPD-weighted hours of being too warm. The researchers reported that the occupants of the office areas were able to control the temperature of their environment, and considered that this apparent comfort anomaly may be accounted for by the influence of adaptive thermal comfort and that this particular population of office users prefer cooler environments. However, they were clear that more investigation was needed (although this was not undertaken in the study).

The building energy use (calculated from the AHU collected data) was assessed and compared with benchmark values. The office and retail areas had annual energy use (electric – fan, heating and cooling) that was considered reasonable (at just over $40kWh{\cdot}m^{-2}$). However, the packing area's was just $7kWh{\cdot}m^{-2}$. It was subsequently determined that the packing area was originally designed as a storage area (with nominal background heating demand), and a supplementary fan coil heating system (which was additional to the monitored systems) had been added so that the area could be used as an occupied space. (This retrofit action was also latterly identified as the cause of the step-change in the monitored supply airflow rates.)

Along with the building fabric and operational information, the adjusted energy data (taking account of the packing area alterations) was used to confirm a 'base case' building thermal model for CAV. Using the now-calibrated model, the team investigated three further scenarios. For VAV and DCV modes, the temperatures were allowed to swing by 2K when the building was unoccupied, as shown in Table 1, and the ventilation rate was allowed to drop to $0.35L{\cdot}s^{-1}{\cdot}m^{-2}$ when the building was unoccupied. One of the significant changes implemented by the scenarios was that there would be controlled temperatures in the spaces – this would overcome not only the overheating as shown in Figure 3b, but also – and possibly more controversially – remove the individual control that previously provided the 'over-cooled' offices of Figure 3a, to maintain them at design temperatures no higher than those specified.

The DCV ventilation rate was determined by modelled occupancy, and was between $0.35L{\cdot}s^{-1}{\cdot}m^{-2}$ and the maximum (CAV) rate.

A DCV 'class 1' system was modelled with the alteration of the indoor temperature set-points to those of class 1 comfort conditions, as provided by EN 15251, as shown in Table 2.

The results of the scenario simulations are shown in Figure 4, and in this case study the implementation of the DCV produced a predicted operational energy saving of more than 50% compared with the simple CAV system.

When considering such an application in a new construction, there will be an impact on capital costs for which there is likely to be an overall additional cost. There will be a reduced size for the AHU as well as the main distribution ducts. However, there will be a need for extra equipment to control the air volume flowrate to the various areas and to ensure good air distribution at reduced flow. The additional investment was estimated by the research team as being an extra 10% and so, in this case, the payback was calculated as less than two years. An improvement in comfort (and potentially a productivity increase) is likely from the enhanced monitoring and control of the internal space, reducing both the building's environmental impact and operating costs – so potentially making the property more marketable. (The team also continued in their analysis to show that by using heat pumps, there were even greater reductions in operating costs that readily exceeded the benefits of using traditional district heating.)

DCV systems have the potential to provide a significant reduction in energy usage when compared with systems with a constant airflow rate, while also achieving good levels of occupant comfort. However, to realise this potential to lower building environmental impact and reduce life-cycle cost requires realistic design that properly accounts for the variability in the specific application.

Turn to page 34 for references.

Energy results

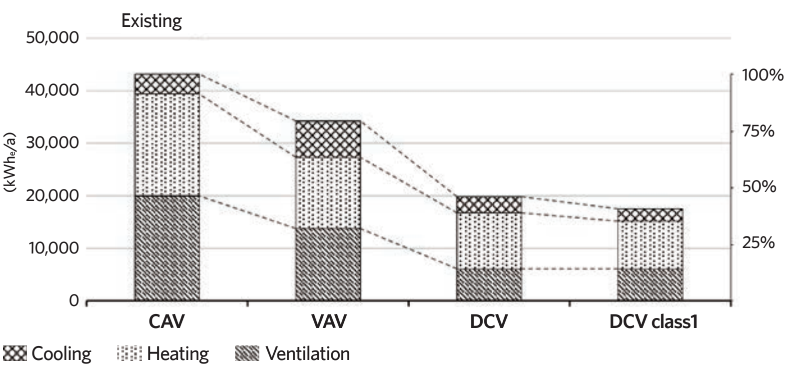


Figure 4: The simulated annual operating cost predictions of the impact of applying the alternative operating scenarios

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Module 148

June 2019

1. What typical occupied rate of rooms in an office block is noted in the article?

☐ A Fewer than 35%-49%

☐ B Fewer than 50%-65%

☐ C Fewer than 66%-74%

☐ D Fewer than 75%-85%

☐ E Fewer than 95%

2. Which area was not included in the studied parts of the Engelsons building?

☐ A First floor area

☐ B Office area

☐ C Packing area

☐ D Retail area

☐ E Warehouse area

3. In the summer period taken as representative of building performance, what was the maximum temperature in the office zone?

☐ A 20°C

☐ B 22°C

☐ C 24°C

☐ D 26°C

☐ E 28°C

4. What standard has recently superseded EN 15251?

☐ A EN 12464-1

☐ B EN 16798-1

☐ C EN ISO 13731

☐ D EN ISO 16000

☐ E EN ISO 7730

5. Approximately, what was the reduction in simulated annual operating cost of using DCV in place of CAV in this case study?

☐ A 30%

☐ B 40%

☐ C 50%

☐ D 60%

☐ E 70%

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2 Bednarova PV *DCV case study on comfort and energy*, **www.swegonairacademy.com/video/swegon-air-academy-seminar-dcv-case-study-comfort-energy/** – accessed 10 May 2019.

3 EN 15251:2007 *Indoor environmental input parameters for design and assessment of energy performance of buildings*, CEN 2007. NOTE now superseded by EN 16798-1:2019.

4 Olesen, BW and deCarli, M, *Long-term evaluation of the general thermal comfort conditions*, Indoor Air 2002, Padova, Italy.

20ºC.
He's okay.

23ºC.
He's feeling warm.

25ºC.
He can't concentrate

29ºC.
He's fading fast.

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