Adaptive thermal comfort in naturally ventilated dormitory buildings in Changsha, China

This research focused on investigating thermal comfort in naturally ventilated (NV) dormitory buildings in hot summer and cold winter (HSCW) climate zone in China. A field study was conducted during the summer of 2016 in Changsha, located in HSCW climate zone. The occupants reported subjective thermal perception using questionnaires and ambient environmental variables were measured simultaneously. A total of 11 NV dormitory buildings were investigated. 467 valid sets of measurement data and subjective questionnaires were obtained. Both Griffiths and linear regression analysis showed that the neutral operative temperature ($T_o$) was 26.2 °C. The upper limit for 80% acceptability was determined as 28.5 °C. The most acceptable operative temperature was 26.6 °C. 80% of occupants were comfortable at the temperature range between 25 °C and 28.7 °C. Based on this study, the adaptive model was developed and verified. The adaptive behaviors of clothing adjustment and air velocity adjustment were closely correlated to indoor $T_o$. The functions of adaptive thermal behaviors can be used for building simulation. The results can be used to assess indoor thermal comfort in buildings, and help to build a more rigorous database for building designing.

Indoor environmental quality, occupant satisfaction, and acute building-related health symptoms in Green Mark-certified compared with non-certified office buildings

Indoor environmental quality (IEQ) has become an important component of green building certification schemes. While green buildings are expected to provide enhanced IEQ, higher occupant satisfaction, and less risks of occupant health when compared with non-green buildings, the literature suggests inconsistent evidence due to diverse research design, small sample size, and weak statistical analysis. This study compared several outcomes pertinent to IEQ performance in green and non-green office buildings in Singapore. Adopting a cross-sectional study design, objective measurements were taken in eight green and six non-green buildings, and satisfaction and acute health symptom risks of 367 occupants were obtained. Green buildings exhibited lower concentration of PM2.5, bacteria, and fungi and maintained temperature and humidity more consistently compared to non-green counterparts. The mean ratings for satisfaction with temperature, humidity, lighting level, air quality, and indoor environment were higher in green buildings (with statistical significance $P < 0.05$). There was statistically significant reduction in risk of occupants having headache, unusual fatigue, and irritated skin in green buildings. Although matching of buildings and occupant characteristics, survey participation bias, and sampling duration (a 1-week snapshot) of IEQ monitoring remain as limitations, this study offered positive association of green buildings with qualitatively and quantitatively measured performance of IEQ.
Physiological and psychological reactions of sub-tropically acclimatized subjects exposed to different indoor temperatures at a relative humidity of 70%

Thermal comfort, self-reported acute health symptoms, cognitive performance, and physiological reactions were examined at four temperatures (26, 30, 33, and 37°C) at a relative humidity of 70%. Thirty-two sub-tropically acclimatized subjects experienced each condition for 175 minutes, in balanced order, in a climatic chamber. The perception of heat gradually increased with increasing temperature, but the subjects felt hot only at 37°C. The temperature of 33°C was on average rated as acceptable and only just uncomfortable. The acceptability of air quality decreased linearly with increasing temperature. The intensity of acute health symptoms reported by the subjects increased with increasing temperature, but it was no more than moderate even at the highest temperature; dryness of skin and eye were alleviated. The eardrum temperature, skin temperature and moisture, heart rate, end-tidal carbon dioxide, and weight loss increased significantly with increasing temperature, whereas the percentage of adjacent heart inter-beat intervals differing by >50 ms decreased significantly. These results suggest that the perceived heat, self-reported symptoms, and physiological reactions occurred concurrently. They show additionally that acclimatization to heat may shift the boundary of thermal discomfort to a higher temperature. The role of psychological adaptation and of the contextual aspects of this process still requires clarification in future experiments.

Proposed metrics for IAQ in low-energy residential buildings

General information
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Organisations: Department of Civil Engineering, Materials and Durability, Indoor Environment, Universite de La Rochelle, Syracuse University
Contributors: Abadie, M., Wargocki, P., Rode, C., Zhang, J.
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The relationship between classroom temperature and children's performance in school
The present paper reports a meta-analysis of published evidence on the effects of temperature in school classrooms on children's performance in school. The data from 18 studies were used to construct a relationship between thermal conditions in classrooms and children's performance in school. Psychological tests measuring cognitive abilities and skills, school tasks including mathematical and language-based tasks, rating schemes, and tests used to assess progress in learning including end-of-year grades and the examination results were considered as indicators of children's performance. Due to the lack of complete measurements, thermal conditions were characterized by measured classroom temperatures. To create the relationship, the fractional change in performance of psychological tests and school tasks was regressed against the average temperature at which the change was recorded; all published data were used regardless of whether the change in learning outcome changed significantly with temperature. For other learning outcomes, no relationship was created because the data were insufficient. The relationship derived in the analysis shows that the performance of psychological tests and school tasks can be expected to increase on average by 20% if classroom temperatures are lowered from 30 °C to 20 °C and that the temperature for optimal performance is lower than 22 °C. The relationship is valid only for temperate climates. It requires verification for other climates and extensions to temperatures lower than 20 °C and higher than 30 °C.

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Organisations: Department of Civil Engineering, Indoor Environment, University of Costa Rica, UNIVERSIDAD DEL BIO-BIO
Corresponding author: Wargocki, P.
Contributors: Wargocki, P., Porras-Salazar, J. A., Contreras-Espinoza, S.
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Emissions from Humans and Indoor Air Chemistry
Ozone-initiated transformation of organic compounds emitted from the human body was studied. Experiments were performed in a unique stainless-steel twin-chamber that enabled the separation and measurements of dermal and exhaled emissions as well as measurements of whole-body emission. When ozone was present in the chamber, levels of...
aldehydes and 6-MHO increased. The reaction products were mainly associated with ozone reacting with the constituents of skin oil.

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**Healthy Indoor Environments: The Need for a Holistic Approach**
Indoor environments have a large impact on health and well-being, so it is important to understand what makes them healthy and sustainable. There is substantial knowledge on individual factors and their effects, though understanding how factors interact and what role occupants play in these interactions (both causative and receptive) is lacking. We aimed to: (i) explore interactions between factors and potential risks if these are not considered from holistic perspective; and (ii) identify components needed to advance research on indoor environments. The paper is based on collaboration between researchers from disciplines covering technical, behavioural, and medical perspectives. Outcomes were identified through literature reviews, discussions and workshops with invited experts and representatives from various stakeholder groups. Four themes emerged and were discussed with an emphasis on occupant health: (a) the bio-psycho-social aspects of health; (b) interaction between occupants, buildings and indoor environment; (c) climate change and its impact on indoor environment quality, thermal comfort and health; and (d) energy efficiency measures and indoor environment. To advance the relevant research, the indoor environment must be considered a dynamic and complex system with multiple interactions. This calls for a transdisciplinary and holistic approach and effective collaboration with various stakeholders.

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Source-ID: 2438770587

This paper summarizes the results of HealthVent project. It had an aim to develop health-based ventilation guidelines and through this process contribute to advance indoor air quality (IAQ) policies and guidelines. A framework that allows determining ventilation requirements in public and residential buildings based on the health requirements is proposed. The framework is based on three principles: 1. Criteria for permissible concentrations of specific air pollutants set by health authorities have to be respected; 2. Ventilation must be preceded by source control strategies that have been duly adopted to improve IAQ; 3. Base ventilation must always be secured to remove occupant emissions (bio-effluents). The air quality guidelines defined by the World Health Organization (WHO) outside air are used as the reference for determining permissible levels of the indoor air pollutants based on the principle that there is only one air. It is proposed that base ventilation should be set at 4 L/s per person; higher rates are to be used only if WHO guidelines are not followed. Implementation of the framework requires technical guidelines, directives and other legislation. Studies are also needed to examine the effectiveness of the approach and to validate its use. It is estimated that implementing the framework would bring considerable reduction in the burden of disease associated with inadequate IAQ.

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Organisations: Department of Civil Engineering, Indoor Environment, University of Milan, University of Porto, Instituto de Engenharia Mecanica e Gestao Industrial - INEGI, National Institute for Health and Welfare, European Commission - Joint Research Center
Contributors: Carrer, P., de Oliveira Fernandes, E., Santos, H., Hänninen, O., Kephalopoulos, S., Wargocki, P.
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Reducing classroom temperature in a tropical climate improved the thermal comfort and the performance of elementary school pupils

Reducing classroom temperature in a tropical climate improved the thermal comfort and the performance of elementary school pupils

A two-week-long intervention study was performed in two classrooms in an elementary school in Costa Rica. Split-cooling air-conditioning (AC) units were installed in both classrooms. During the first week, the air temperature was reduced in one classroom while in the other (placebo) classroom the fans were operated but no cooling was provided. During the second week, the conditions were exchanged to create a 2 x 2 crossover design in which each pupil was their own control. A total of 37 children performed tasks similar to school work and completed questionnaires reporting their thermal sensation and perceptions. Operating the AC units reduced classroom temperature by about 5 K, from about 30 to 25 degrees C. Thermal sensations changed from hot to neutral and slightly cold, and the percentage of children rating the thermal conditions as acceptable increased significantly. Neutral temperature was estimated to be about 27 degrees C. The 11-year-old children performed the language and logical-thinking tasks significantly better in terms of speed at the lower temperature, while the less able pupils performed better on all tasks at the lower temperature. There were no significant effects on accuracy. These results confirm published findings from moderate climates and extend their validity to the tropics. They indicate that acclimatization can increase the optimal temperature for learning.

General information
Retrofit of school ventilation and pupil well-being and performance being and performance – ASHRAE RP1624
This intervention study compared five solutions for retrofitting school ventilation. No systematic effect of the system operation mode (on or off) on pupils' wellbeing, symptoms, or performance was observed, but there were significant associations between the performance of some tasks and the classroom CO2 concentration and temperature.

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Sensory evaluation and chemical analysis of exhaled and dermally emitted bioeffluents
Conditions in which exhaled and dermally emitted bioeffluents could be sampled separately or together (whole-body emission) were created. Five lightly dressed males exhaled the air through a mask to another, identical chamber or without a mask to the chamber in which they were sitting; the outdoor air supply rate was the same in both chambers. The carbon dioxide concentration in the chamber with exhaled air was 2000 ppm. Chamber temperatures were 23°C or 28°C, and ozone was present or absent in the supply airflow. When dermally emitted bioeffluents were present, the perceived air quality (PAQ) was less acceptable, and the odor intensity was higher than when only exhaled bioeffluents were present. The presence or absence of exhaled bioeffluents in the unoccupied chamber made no significant difference to sensory assessments. At 28°C and with ozone present, the odor intensity increased and the PAQ was less acceptable in the chambers with whole-body bioeffluents. The concentrations of nonanal, decanal, geranylacetone, and 6-MHO were higher when dermally emitted bioeffluents were present; they increased further when ozone was present. The concentration of squalene then decreased and increased again at 28°C. Dermally emitted bioeffluents seem to play a major role in the sensory nuisance experienced when occupied volumes are inadequately ventilated.
The effects of cement-based and cement-ash-based mortar slabs on indoor air quality

The effects of emissions from cement-based and cement-ash-based mortar slabs were studied. In the latter, 30% of the cement content had been replaced by sewage sludge ash. They were tested singly and together with either carpet or linoleum. The air exhausted from the chambers was assessed by means of odour intensity and chemical characterization of emissions. Odour intensity increased with the increased exposed area of the slabs. It did not differ significantly between cement-based or cement-ash-based mortar and neither did the chemical composition of the exhaust air. A significant sink effect was observed when linoleum was added to any of the two slabs examined. The sink effect increased as the exposed area of the slabs was increased. The odour intensity of the mixture of the slab and linoleum was lower than the intensity of odour produced by any of the two materials when tested singly. A plausible explanation for this effect was that the mortar slabs adsorbed the organic acids that were emitted at a high rate from linoleum, mortar being strong base. The same sink effect was also observed when the mortar slabs were exposed together with carpet but it was much smaller because the carpet emitted smaller quantities of acids. The total concentration of organic compounds measured was not appreciably different when the slabs were tested alone or together with linoleum or carpet. Considerable differences in the concentration of organic compounds were however observed when the total concentration of each functional group was calculated and compared.
Thermal environment, IAQ and sleep
Is sleep becoming so much scarcer than ever before because people do not realize the importance of sleep for health and well-being? All over the world, digital communications now mean that contact with work continues after hours and during weekends and that "friends" are no longer just the people we meet regularly, but the many more we contact regularly. These new contacts compete strongly for our time with online entertainment and news, our leisure activities and our immediate families, and there are still only 24 hours in each day.

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Contributors: Wargocki, P., Lan, L., Lian, Z., Wyon, D. P.
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Window and door opening behavior, carbon dioxide concentration, temperature, and energy use during the heating season in classrooms with different ventilation retrofits—ASHRAE RP1624
The aim of the present study was to extend the knowledge on the suitability and performance of different ventilation retrofit solutions for school buildings located in a temperate climate. A unique approach was used, where four similar and adjacent classrooms in the same school unit located north of Copenhagen, Denmark, were retrofitted either with a decentralized, balanced supply and exhaust mechanical ventilation unit with heat recovery; automatically operable windows with an exhaust fan; automatically operable windows with alternating counter-flow heat recovery through slots in the outside wall; or a visual feedback display unit showing the current classroom carbon dioxide concentration, thus advising when the windows should be opened. For comparison, one classroom retained the original approach for achieving ventilation by manual opening of windows. One year after retrofitting the classrooms carbon dioxide concentrations, temperatures, energy use, and window and door opening behavior were recorded during a four week period in the heating season in January. The measured carbon dioxide concentrations were significantly lower in the classrooms with the mechanical ventilation system and the system with automatic window opening and an exhaust fan as compared with the classrooms with automatic window opening and heat recovery, with visual carbon dioxide feedback and where windows were opened manually. The automatically controlled windows were open for 71% of the occupied time including breaks with an exhaust fan and for 49% with heat recovery. The façade windows were open up to 17% of the occupied time including breaks in the classrooms with manual window opening (with or without visual feedback). The classroom temperature was generally within the recommended thermal comfort range. The present results indicate that in temperate climates the mechanical ventilation system and both systems with automatic window opening are the recommended systems for classrooms in temperate climates. Providing simply visual feedback on the current carbon dioxide concentration, as a motivation for window opening, did not do so.

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Organisations: Section for Indoor Climate and Building Physics, Department of Civil Engineering, Danish Technological Institute
Source-ID: 2400092253
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Effects of Exposure to Carbon Dioxide and Bioeffluents on Perceived Air Quality, Self-assessed Acute Health Symptoms and Cognitive Performance

The purpose of this study was to examine the effects on humans of exposure to carbon dioxide (CO\textsubscript{2}) and bioeffluents. In three of the five exposures, the outdoor air supply rate was high enough to remove bioeffluents, resulting in a CO\textsubscript{2} level of 500 ppm. Chemically pure CO\textsubscript{2} was added to this reference condition to create exposure conditions with CO\textsubscript{2} at 1,000 ppm or 3,000 ppm. In two further conditions, the outdoor air supply rate was restricted so that the bioeffluent CO\textsubscript{2} reached 1,000 ppm or 3,000 ppm. The same twenty-five subjects were exposed for 255 minutes to each condition. Subjective ratings, physiological responses and cognitive performance were measured. No statistically significant effects on perceived air quality, acute health symptoms or cognitive performance were seen during exposures when CO\textsubscript{2} was added. Exposures to bioeffluents with CO\textsubscript{2} at 3,000 ppm reduced perceived air quality, increased the intensity of reported headache, fatigue, sleepiness and difficulty in thinking clearly, and reduced speed of addition, the response time in a redirection task and the number of correct links made in the cue-utilisation test. This suggests that moderate
concentrations of bioeffluents, but not pure CO₂, will result in deleterious effects on occupants during typical indoor exposures.

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Organisations: Department of Civil Engineering, Section for Indoor Climate and Building Physics, Department of Applied Mathematics and Computer Science, Statistics and Data Analysis, Shanghai Jiao Tong University
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Klimavenlig beton

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Performance, acute health symptoms and physiological responses during exposure to high air temperature and carbon dioxide concentration
Human subjects were exposed for 3 h in a climate chamber to the air temperature of 35 °C that is an action level, at which the working time needs to be diminished in China. The purpose was to put this action level to test by measuring physiological responses, subjective ratings and cognitive performance, and compare them with responses at temperature of 26 °C (reference exposure). Moreover, CO₂ was increased to 3000 ppm (CO₂ exposure) at 35 °C to further examine, whether this change will have any effect on the measured responses. Compared with the reference exposure, exposure to 35 °C caused subjects to report feeling uncomfortably warm, to rate the air quality as worse, to report increased sleepiness and higher intensity of several acute health symptoms. Eardrum temperature, skin temperature, heart rate and body weight loss all increased significantly at this exposure, arterial oxygen saturation decreased significantly, while the
percentage of adjacent inter-beat cardiac intervals differing by > 50 m (pNN50) decreased significantly, indicating elevated stress. The performance of addition and subtraction tasks decreased significantly during this exposure, as well. Increasing CO₂ to 3000 ppm at 35 °C caused no significant changes in responses. Present results reaffirm the selection of 35 °C as an action level, and show that concurrently occurring high CO₂ levels should not exacerbate the hazards.

**General information**

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Contributors: Liu, W., Zhong, W., Wargocki, P.
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**Physiological responses during exposure to carbon dioxide and bioeffluents at levels typically occurring indoors**

Twenty-five subjects were exposed to different levels of carbon dioxide (CO₂) and bioeffluents. The ventilation rate was set high enough to create a reference condition of 500 ppm CO₂ with subjects present; additional CO₂ was then added to supply air to reach levels of 1000 or 3000 ppm, or the ventilation rate was reduced to allow metabolically generated CO₂ to reach the same two levels (bioeffluents increased as well). Heart rate, blood pressure, end-tidal CO₂ (ETCO₂), oxygen saturation of blood (SPo₂), respiration rate, nasal peak flow, and forced expiration were monitored, and the levels of salivary α-amylase and cortisol were analyzed. The subjects performed a number of mental tasks during exposures and assessed their levels of comfort and the intensity of their acute health symptoms. During exposure to CO₂ at 3000 ppm, when CO₂ was added or ventilation was restricted, ETCO₂ increased more and heart rate decreased less than the changes that occurred in the reference condition. Exposure to bioeffluents, when metabolically generated CO₂ was at 3000 ppm, significantly increased diastolic blood pressure and salivary α-amylase level compared with pre-exposure levels, and reduced the performance of a cue-utilization test: These effects may suggest higher arousal/stress. A model is proposed describing how mental performance is affected by exposure to bioeffluents.

**General information**

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- Scopus rating (2017): CiteScore 3.9
Responses to Human Bioeffluents at Levels Recommended by Ventilation Standards

The purpose of this study was to examine whether exposure to human bioeffluents, at the levels recommended by the current ventilation standards, would cause any effects on humans. Ten subjects were exposed in a low-emission stainless-steel climate chamber for 4.25 hours. The outdoor air supply rate was set to 33 or 4 l/s per person, creating two levels of bioeffluents with carbon dioxide (CO₂) at 500 or 1600 ppm. Subjective ratings were collected, cognitive performance was examined and physiological responses were monitored. The results show that exposures to human
bioeffluents at ventilation rate of 4 l/s per person caused sensory discomfort of visitors, reduced pNN50 (a domain of ECG measurement), but did not produce negative effects on cognitive performance or health symptoms.

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Corresponding author: Zhang, X.
Contributors: Zhang, X., Wargocki, P., Lian, Z., Xie, J., Liu, J.
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Source-ID: 85033400082
Research output: Contribution to journal – Conference article – Annual report year: 2017 – Research – peer-review

### Ten questions concerning green buildings and indoor air quality

This paper investigates the concern that green buildings may promote energy efficiency and other aspects of sustainability, but not necessarily the health and well-being of occupants through better indoor air quality (IAQ). We ask ten questions to explore IAQ challenges for green buildings as well as opportunities to improve IAQ within green buildings and their programs. Our focus is on IAQ, while recognizing that many factors influence human health and the healthfulness of a building. We begin with an overview of green buildings, IAQ, and whether and how green building certifications address IAQ. Next, we examine evidence on whether green buildings have better IAQ than comparable conventional buildings. Then, we identify so-called green practices and green products that can have unintended and unfavorable effects on IAQ. Looking ahead, we offer both immediate and longer-term actions, and a set of research questions, that can help green buildings to more effectively promote IAQ. This article supports a growing recognition of the importance of IAQ in green buildings, and the opportunities for improvements. As the World Green Building Council [95] and others have emphasized, people are the most valuable asset of organizations, and efforts to improve IAQ can improve health, well-being, productivity, and profitability.

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Web of Science (2017): Impact factor 4.539
Web of Science (2017): Indexed yes
Ten questions concerning thermal and indoor air quality effects on the performance of office work and schoolwork

Energy conservation in buildings as a way to reduce the emission of greenhouse gases is forcing an urgent re-examination of how closely thermal and air quality conditions should be controlled in buildings. Allowing conditions to drift outside the optimum range would conserve very large amounts of energy and would in most cases have only marginal effects on health or subjective comfort. The question that then arises is whether occupant performance would be negatively affected and if so, by how much. This information is required for cost-benefit analyses. The answers in this paper are based on laboratory and field experiments that have been carried out since the massive increase in energy costs that took place in the 1970s. Although only a few of the mechanisms by which indoor environmental effects occur have been identified, it is already clear that any economies achieved by energy conservation will be greatly exceeded by the costs incurred due to decreased performance. Reducing emissions by allowing indoor environmental conditions to deteriorate would thus be so expensive that it would justify greatly increased investment in more efficient use of energy in buildings in which conditions are not allowed to deteriorate. Labour costs in buildings exceed energy costs by two orders of magnitude, and as even the thermal and air quality conditions that the majority of building occupants currently accept can be shown to reduce performance by 5e10% for adults and by 15e30% for children, we cannot afford to allow them to deteriorate still further.

Towards the definition of indicators for assessment of indoor air quality and energy performance in low-energy residential buildings

A major obstacle for integrating energy and indoor air quality (IAQ) strategies in the design and optimization of buildings is the non-existence of an agreed measure, which can quantitatively describes the IAQ and will allow the assessment of measures to improve energy performance. A complication to develop such an IAQ index is that hundreds of chemical compounds are present in indoor air, including residential environments, at concentrations much lower than occurring during occupational exposures. There is a lack of clear consensus on which pollutant or group of pollutants should be used to form such an index as well as on how they should be integrated into one index. IEA EBC Annex 68 was formed with the objective to discuss Indoor Air Quality Design and Control in Low Energy Residential Buildings. The objective of
Subtask 1 of this Annex described in this paper was to review, discuss and propose methods and approaches to define an IAQ index and to develop such an index so that it can be used as a key performance indicator to examine the methods to control IAQ, which are integral parts of other subtasks in this IEA EBC project. To meet this objective, the pollutants measured in low-energy houses were compared with pollutants measured in traditional houses. Pollutants measured and known to be harmful for health were identified and selected to be represented on a list of pollutants that should be considered when the IAQ index is defined. The selected pollutants were: acetaldehyde, acrolein, α-pinene, benzene, carbon dioxide, formaldehyde, naphthalene, nitrogen dioxide, PM10, PM2.5, radon, styrene, toluene, trichloroethylene, TVOC and mould. Both short-term and long-term effects of these pollutants were considered. The compound with the highest ratio of concentration to its exposure limit value was proposed as the IAQ index for the short term effects so that the existing exposure limits could be referred to and to avoid problems associated with the aggregation of many air quality indices. The same approach was proposed for the IAQ index for the long-term effects together with the calculation of the burden of disease caused by the compounds of concern expressed as the sum of disability-adjusted life years. It is recognized that the proposed IAQ indices are crude, and the list of compounds is incomplete. It should be progressively updated once new data on exposure limits and pollutants of concern become available.

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Do new and renovated schools and kindergartens secure sufficiently high indoor environmental quality?
The present work is the part of the RENEW SCHOOL project granted by the Intelligent Energy Europe programme supported by European Commission. The aim is to promote sustainable renovation of educational buildings (schools and kindergartens) that use timber facades. The paper describes the measurements in educational buildings that are newly constructed or that have undergone energy renovation and use timber facades. The purpose of the measurements was to examine the quality of indoor environment in these buildings. The quality was assessed by physical measurements of temperature, relative humidity, light intensity and carbon dioxide concentration performed for a period of up to two month between January and April 2015. The measurements were carried out in one representative classroom in each building. The pupils assessed the classroom environment and rated the intensity of their acute health symptoms. Additionally the teachers assessed the environment in these buildings. To create the reference, measurements were also carried out in five conventional educational buildings, where no renovations were performed. The results suggest that the renovated and new buildings perform more or less similar as their conventional counterparts as regards measured parameters of indoor environment. Subjective evaluations made by pupils and teachers did not always match the physical measurements. There were also differences in subjective evaluations made by children and by teachers. In conclusion, there is no indication that the renovation of educational buildings would reduce indoor environmental quality conditions. Likewise, no considerable improvements are to be expected as well.

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Effects on pupil well-being and performance of classroom ventilation retrofits – ASHRAE RP1624
This study examines the effect on classroom indoor climate, pupil well-being, school performance, and energy consumption of four different retrofit solutions to improve classroom ventilation.

Human responses to carbon dioxide, a follow-up study at recommended exposure limits in non-industrial environments
To extend the results of a previous study on the effects of carbon dioxide (CO₂) and bioeffluents on humans, the new study reported in this paper was carried out. The purpose of this study was to examine, whether exposure to CO₂ at 5000 ppm would cause sensory discomfort, evoke acute health symptoms, reduce the performance of cognitive tasks, or result in changes in physiological responses. The outdoor air supply rate was set high enough in a low-emission stainless-steel climate chamber to create a reference condition with CO₂ at 500 ppm when subjects were present, and chemically pure CO₂ was added to the supply air to create an exposure condition with CO₂ at 5000 ppm (the measured exposure level was ca. 4900 ppm). Ten healthy college-age students were exposed twice to each of the two conditions for 2.5 h in a design balanced for order of presentation. The raised CO₂ concentration had no effect on perceived air quality or physiological responses except for end-tidal CO₂ (ETCO₂), which increased more (to 5.3 kPa) than it was in the reference condition (5.1 kPa). Other results indicate additionally that a 2.5-h exposure to CO₂ up to 5000 ppm did not increase intensity of health symptoms reported by healthy young individuals and their performance of simple or moderately difficult cognitive tasks and some tasks resembling office work. These results accord well with the current occupational exposure limit recommendation for CO₂ and with many other reports published in the literature.
Measurements of Dermal and Oral Emissions from Humans

Human related pollutants (bioeffluents) emitted through skin and via exhaled breath were measured. Two climate chambers were connected via flexible ducts. The ducts were in one chamber attached to a breathing mask, through which five subjects exhaled on one occasion the air into the other chamber: Human bioeffluents emitted orally were in this way isolated from those that were emitted dermally. On another occasion, the subjects exhaled the air into the chamber where they were sitting, thus exposure contained oral and dermal bioeffluents. Another twenty subjects assessed the air quality in the chambers. They judged the air quality in the chamber with dermal bioeffluents to be lower than in the one containing orally exhaled bioeffluents, and similar to the air quality in the chamber with all bioeffluents. The chemical compounds with slightly elevated concentrations differed between the two chambers.

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Reducing burden of disease from residential indoor air exposures in Europe (HEALTHVENT project)

Background: The annual burden of disease caused indoor air pollution, including polluted outdoor air used to ventilate indoor spaces, is estimated to correspond to a loss of over 2 million healthy life years in the European Union (EU). Based on measurements of the European Environment Agency (EEA), approximately 90 % of EU citizens live in areas where the World Health Organization (WHO) guidelines for air quality of particulate matter sized <2.5 mm (PM$_{2.5}$) are not met. Since sources of pollution reside in both indoor and outdoor air, selecting the most appropriate ventilation strategy is not a simple and straightforward task.

Methods: A framework for developing European health-based ventilation guidelines was created in 2010–2013 in the EU-funded HEALTHVENT project. As a part of the project, the potential efficiency of control policies to health effects caused by residential indoor exposures of fine particulate matter (PM$_{2.5}$), outdoor bioaerosols, volatile organic compounds (VOC), carbon oxide (CO) radon and dampness was estimated. The analysis was based on scenario comparison, using an outdoor-indoor mass-balance model and varying the ventilation rates. Health effects were estimated with burden of diseases (BoD) calculations taking into account asthma, cardiovascular (CV) diseases, acute toxication, respiratory infections, lung cancer and chronic obstructive pulmonary disease (COPD).

Results: The quantitative comparison of three main policy approaches, (i) optimising ventilation rates only; (ii) filtration of outdoor air; and (iii) indoor source control, showed that all three approaches are able to provide substantial reductions in the health risks, varying from approximately 20 % to 44 %, corresponding to 400 000 and 900 000 saved healthy life years in EU-26. PM$_{2.5}$ caused majority of the health effects in all included countries, but the importance of the other pollutants varied by country.

Conclusions: The present modelling shows, that combination of controlling the indoor air sources and selecting appropriate ventilation rate was the most effective to reduce health risks. If indoor sources cannot be removed or their emissions cannot be limited to an accepted level, ventilation needs to be increased to remove remaining pollutants. In these cases filtration of outdoor air may be needed to prevent increase of health risks.
Sensory ratings of emissions from nontraditional building materials

Twenty-five subjects assessed the emissions from building materials: linoleum, cement mortar with and without fly ash, gypsum board and tiles with air cleaning properties and natural organic sheep wool. The ratings were made at different material loadings and in combinations with linoleum. The results showed that except for natural organic product, increasing loading and combining materials with linoleum increased intensity of odor.

The effects of bedroom air quality on sleep and next-day performance

Twenty-five subjects assessed the emissions from building materials: linoleum, cement mortar with and without fly ash, gypsum board and tiles with air cleaning properties and natural organic sheep wool. The ratings were made at different material loadings and in combinations with linoleum. The results showed that except for natural organic product, increasing loading and combining materials with linoleum increased intensity of odor.
Association between classroom ventilation mode and learning outcome in Danish schools

Associations between learning, ventilation mode, and other classroom characteristics were investigated with data from a Danish test scheme and two widespread cross-sectional studies examining air quality in Danish schools. An academic achievement indicator as a measure of the learning outcome was calculated from the scores of a standardized Danish test scheme adjusted for a socioeconomic reference index. Pupils in schools with balanced mechanical ventilation had significantly higher achievement indicators than pupils in schools with natural ventilation, where airing took place mostly by manual window opening. Also, the carbon dioxide concentration was lower in classrooms with balanced mechanical ventilation. There was no consistent association between the achievement indicators and the person specific room volume, construction/renovation year, or the occupancy. Measurements of carbon dioxide concentrations and temperatures in 820 classrooms in 389 schools were available. In 56% and 66% of the classrooms included in the two studies, the measured CO₂ concentration was higher than 1000ppm. The findings of this study add to the growing evidence that insufficient classroom ventilation have impacts on learning outcomes.
Can we establish relationship between outdoor air ventilation and health based on the published epidemiological data?

Appropriate exposure control is prerogative for reducing the burden of disease (BOD) due to inadequate air quality indoors (IAQ). Ventilation with outdoor air is one of the available exposure control methods and is widespread. It is often assumed that this method will bring tangible effects on health. This paper examines whether the available archival epidemiological evidence provides information on the link between outdoor air ventilation and health that can be used for regulative purposes, when ventilation requirements for non-industrial built environments are set. To achieve this goal, multidisciplinary review was carried out of the scientific literature on health and outdoor air ventilation in non-industrial indoor environments (not covered by previous reviews on this topic) and of major reviews on this topic. The results show, that effects on health were seen for wide range of ventilation rates from 6-7 L/s per person, which were the lowest ventilation rates, at which no effects on some health outcomes were observed in field studies, until 25-40 L/s per person, which were in some studies the highest ventilation rates needed so no effects on health outcomes were seen. The actual contaminant exposures at various levels of ventilation were no characterized. It was observed that available data have many limitations, such as insufficient statistical power, incomplete data on the strength of pollution sources, diversity and variability of ventilation rates, at which effects have been seen, no standardized duration of exposures and diversity of the outcomes, as well as different sensibility of populations exposed. The health-ventilation relationship cannot thus competently be established, also because it must be admitted that outdoor air ventilation is only indirectly related to health by modifying exposures affecting health. It is concluded, that currently available epidemiological data do not provide sound basis for outdoor air ventilation requirements that can be universally applicable in different public and residential buildings to protect against health risks. They show minimum rates at which some health outcomes can be avoided, but these may not be generalized for the entire population of buildings, and thus cannot be used for setting minimum standards and/or regulations. Consequently, ventilation should not be advocated as the only solution to modify exposures, and should be implemented together with, and preferably after, other methods of controlling exposures have been fully exploited.
Comparative analysis of modified PMV models and SET models to predict human thermal sensation in naturally ventilated buildings

In this paper, a comparative analysis was performed on the human thermal sensation estimated by modified predicted mean vote (PMV) models and modified standard effective temperature (SET) models in naturally ventilated buildings; the data were collected in field study. These prediction models were developed on the basis of the original PMV/SET models and consider the influence of occupants' expectations and human adaptive functions, including the extended PMV/SET models and the adaptive PMV/SET models. The results showed that when the indoor air velocity ranged from 0 to 0.2 m/s and from 0.2 to 0.8 m/s, the expectancy factors for the extended PMV model and the extended SET model were from 0.770 to 0.974 and from 1.330 to 1.363, and the adaptive coefficients for the adaptive PMV model and the adaptive SET model were from 0.029 to 0.167 and from 0.213 to 0.195. In addition, the difference in thermal sensation between the measured and predicted values using the modified PMV models exceeded 25%, while the difference between the measured thermal sensation and the predicted thermal sensation using modified SET models was approximately less than 25%. It is concluded that the modified SET models can predict human thermal sensation more rationally and accurately compared with the modified PMV models in naturally ventilated buildings probably because air velocity has a strong effect on human thermal sensation in naturally ventilated buildings.
Effects of Exposure to Carbon Dioxide and Human Bioeffluents on Cognitive Performance

The purpose of this study was to examine whether exposures to CO2 in the range of 500 ppm to 3,000 ppm with and without bioeffluents influence cognitive performance. Twenty-five subjects were exposed in the climate chamber for 255 minutes. Cognitive performance was examined by multiple tasks including proof-reading, addition, subtraction, text typing, neurobehavioral tests, Tsai-Partington task, and d2 attention task. Subjective ratings of comfort and experienced acute health symptoms were collected, physiological responses of subjects were monitored and the saliva samples were collected to analyze stress biomarkers. The results show that during exposure to bioeffluents with CO2 reaching 3,000 ppm speed of addition was significantly reduced, subjects responded significantly quicker in redirection task and completed significantly less correct links in Tsai-partington test, which may imply that arousal (stress level) was an underlying mechanism. (C) 2015 Published by Elsevier Ltd.
Physiological responses to exposure to carbon dioxide and human bioeffluents
Present paper describes physiological responses as a result of exposures to CO2 (between 500 ppm to 3,000 ppm) with and without bioeffluents. Twenty-five subjects participated. They were exposed in the climate chamber for 255 minutes in groups of five at a time. During exposure, they performed different cognitive tasks and assessed their comfort and acute health symptoms. Besides, the following were determined: heart rate, blood pressure, oxygen saturation of blood, respiration rate, minute ventilation rate, nasal peak flow, forced expiratory volume, and the end-tidal CO2 pressure (ETCO2). Saliva samples were collected to analyze stress biomarkers. During exposure to CO2 with and without bioeffluents at 3,000 ppm, ETCO2 and minute ventilation rate were higher, while nasal peak flow decreased. These exposures caused also the increased heart rate during typing sessions. During exposures to CO2 with bioeffluents, the performance of Tsai-Partington test was reduced, and diastolic blood pressure and alpha-amylase increased after exposure compared with their levels before exposure, which may suggest higher arousal/stress. During exposure to CO2 without bioeffluents, the performance of Tsai-Partington test also was lower, which may suggest higher stress/arousal, too. However, no effects on blood pressure and alpha-amylase were seen for this exposure.

Use of visual CO2 feedback as a retrofit solution for improving classroom air quality
Carbon dioxide (CO2) sensors that provide a visual indication were installed in classrooms during normal school operation. During 2-week periods, teachers and students were instructed to open the windows in response to the visual CO2 feedback in 1 week and open them, as they would normally do, without visual feedback, in the other week. In the heating season, two pairs of classrooms were monitored, one pair naturally and the other pair mechanically ventilated. In the cooling season, two pairs of naturally ventilated classrooms were monitored, one pair with split cooling in operation and the other pair with no cooling. Classrooms were matched by grade. Providing visual CO2 feedback reduced CO2 levels, as more windows were opened in this condition. This increased energy use for heating and reduced the cooling requirement in summertime. Split cooling reduced the frequency of window opening only when no visual CO2 feedback was present.
Ventilationens betydning for indlæring i skoler

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What are indoor air quality priorities for energy-efficient buildings?

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What does the scientific literature tell us about the ventilation-health relationship in public and residential buildings?

Objective of this paper is to examine whether the available epidemiological evidence provides information on the link between outdoor air ventilation rates and health, and whether it can be used for regulatory purposes when setting ventilation requirements for non-industrial built environments.

Effects on health were seen for a wide range of outdoor ventilation rates from 6 to 7 L/s per person, which were the lowest ventilation rates at which no effects on any health outcomes were observed in field studies, up to 25–40 L/s per person, which were in some studies the lowest outdoor ventilation rates at which no effects on health outcomes were seen. These data show that, in general, higher ventilation rates in many cases will reduce health outcomes, and that there are the minimum rates, at which some health outcomes can be avoided. But these data have many limitations, such as crude estimation of outdoor ventilation rates, diversity and variability of ventilation rates at which effects were seen, a diversity of outcomes (in case of health outcomes being mainly acute not chronic). Among other limitations there are incomplete data on the strength of pollution sources and exposures as well as a wide range of sensibility of the exposed populations.

The available data do not provide a sound basis for determining specific outdoor air ventilation rates that can be universally applicable in different public and residential buildings to protect against health risks. They cannot be used for regulative purposes, unless the required ventilation rates are related to actual exposures and are prescribed only when full advantage of other methods for controlling exposures has been taken.

Cerebral blood flow, fatigue, mental effort, and task performance in offices with two different pollution loads

The effects of indoor air quality on symptoms, perceptions, task performance, cerebral blood flow, fatigue, and mental effort of individuals working in an office were investigated. Twenty-four right-handed Danish female subjects in an office were exposed in groups of two at a time to two air pollution levels created by placing or removing a pollution source (i.e. a used carpet) behind a screen. During the exposure, the subjects performed four different office tasks presented on a computer monitor. The tasks were performed at two paces: normal and maximum. When the pollution source was present, the air quality was perceived to be worse and more errors were made when subjects typed text at the maximum pace. No other changes in subjective responses, performance, or physiological measurements were associated with different
exposures. Although cerebral blood flow and voice analysis did not detect any effects caused by modifying pollution exposure, they were well correlated with increased mental effort when the tasks were performed at maximum pace and subjectively reported fatigue, which increased during the course of exposure, respectively.

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**Classroom ventilation type and pupil learning**

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**Do Certified Buildings Enhance Indoor Environmental Quality and Performance of Office Work?**
With the growth of sustainability consciousness, the awareness of stakeholders for high performance buildings has also increased. The concept of green buildings has appeared. Several voluntary environmental rating schemes for buildings were created. Their focus has been energy conservation and environmental impacts. The schemes use different credit system for various variables and different approaches to rate indoor environmental quality (IEQ) (Figure 1). It is interesting to examine, whether human related factors are properly addressed in the schemes, especially considering the potential effects on productivity and that an average employee cost can be >10-100 times higher than the rental operation and maintenance costs (Morrell, 2005; Persram et al., 2007). There is however lack of consistent and systematic data benchmarking benefits of green building, in particular as regards IEQ and the effects on humans. Health, comfort and work performance outcomes are more difficult to quantify than the effects on energy. As a result, it may be expected that credits for IEQ in the schemes be traded with other credits. If so, although claimed to have an outstanding IEQ as compared with conventional buildings (Lee, 2011), the green building do not have to necessarily meet this postulation.
Quite limited numbers of credits for enhancing IEQ offered by the schemes will certainly not very much help that the high IEQ is guaranteed. The present paper surveyed literature on green buildings to examine whether there is any systematic evidence that these buildings outperform conventional buildings as regards IEQ either through actual IEQ measurements, subjective assessments made by occupants and/or objectively and self-estimated work performance.

Guidelines For Health-Based Ventilation In Europe
The burden of disease (BoD) associated with major air exposures indoors in 26 European countries was recently accounted for loss of two million healthy life years annually expressed as disability adjusted life years (DALYs) (Jantunen et al., 2011). The development of health-based ventilation guidelines has been recommended as one of the strategic priorities to reduce this BoD (de Oliveira-Fernandes et al., 2009), also because the current ventilation standards in Europe provide different categories of comfort, not health, as the main criteria for designing ventilation requirements (EN 13779, 2007). HealthVent project was granted by the European Commission through the Second Programme of Community Action in the Field of Health 2008-2013 to develop the principles of such guidelines. This paper describes the results of this project.

ISIAQ Academy Awards 2014
The 13th International Conference on Indoor Air Quality and Climate (Indoor Air 2014) was convened in Hong Kong during the week of 7–12 July 2014. Professor Yuguo Li served as the Conference President. One of many highlights was the presentation of awards from the ISIAQ Academy of Fellows, which occurred during the opening plenary session. These awards celebrate high achievements in the indoor air sciences. As described in an earlier editorial (Nazaroff, 2012a), the ISIAQ Academy of Fellows has its origins in the creation of the International Academy of Indoor Air Sciences in 1991. In 2005, that organization was reconstituted as a part of the International Society of Indoor Air Quality and Climate (ISIAQ). The ISIAQ Academy of Fellows is an international, multidisciplinary, scientific, honorific organization established to promote scholarship in the indoor environment and building sciences. The awards program, which is featured at all Indoor Air conferences, is a core activity of the Academy.
Literature Survey on the Effects of Pure Carbon Dioxide on Health, Comfort and Performance

Carbon dioxide ($CO_2$) is one of the components of the earth atmosphere. It is also a significant human metabolite. It is colourless and odourless gas. The background levels of $CO_2$ in ambient air are about 350-400 ppm. Its concentration in buildings can be an order of magnitude higher reaching even 4,000-4,500 ppm (Menå and Larsen, 2010). The indoor levels of $CO_2$ depend mainly on human occupancy ($CO_2$ producing processes) and the frequency of air renewal (outdoor air exchange rate). Since studies of Pettenkofer in the 19th century, the levels of indoor $CO_2$ have been used as an indicator of air quality in buildings (Pettenkofer, 1858), as well as quantity and effectiveness of ventilation in the presence of people; the levels above 1,000 ppm have been generally considered to cause unacceptable air quality; the levels above 2,000 ppm are considered as the levels requiring actionable decisions. The 8-hour permissible occupational exposure level to $CO_2$ is set at 5,000 ppm (ACGIH, 2011). Although in many studies $CO_2$ has been related with health symptoms, comfort and performance of office work and schoolwork, it in itself has traditionally been assumed innocuous at the typical levels indoors; in these studies, $CO_2$ was merely a proxy for elevated exposure levels to air pollutants, and an indicator of inadequate outdoor air ventilation and poor indoor air quality. Two recent experiments suggest however that the exposure to pure $CO_2$ at the levels typically occurring indoors and lower than the levels prescribed as permissible by the occupational standards can have negative effects on some aspects of human performance, in particular on tasks requiring concentration (Kajtar et al., 2006) and on tasks, in which decision should be taken (Satish et al., 2012). The present paper reports the results of the literature survey aimed to summarize the published evidence on the effects of pure $CO_2$ on humans and, if possible, to suggest the underlying mechanisms.

Occupant Time Period of Thermal Adaption to Change of Outdoor Air Temperature in Naturally Ventilated Buildings

The present work proposed a method to determine time period of thermal adaption of occupants in naturally ventilated building, based on the relationship between their neutral temperatures and running mean outdoor air temperature. Based on the data of the field investigation, the subjects’ time period of thermal adaption was obtained with the proposed method. The result revealed that the subjects needed to take 4.25 days to fully adapt to a step-change in outdoor air temperature. The time period of thermal adaption for the occupants in five European countries was also calculated and compared with the value of the subjects in this study. The comparison shows that the occupants in China had a shorter time period of thermal adaption than European occupants, which means that Chinese occupants can adapt to a new outdoor climate condition faster.
Outdoor air dominates burden of disease from indoor exposures
Both indoor and outdoor sources of air pollution have significant public health impacts in Europe. Based on quantitative modelling of the burden of disease the outdoor sources dominate the impacts by a clear margin.

Seasonal differences in human responses to increasing temperatures
Experiments were conducted in late summer and winter with 80 young and elderly Danish subjects exposed for 3.5 hours in a climate chamber to the temperature increasing from 24°C to 35.2°C at a rate of 3.7K/h. Psychological and physiological measurements were performed during exposure and subjects assessed comfort and acute health symptoms. Thermal sensation increased with increasing chamber temperature and did not differ during late summer and winter exposures. Skin temperature increased with increasing temperature and was slightly but significantly higher in the late summer in the first half of exposure. Core temperature started to increase, when the chamber temperature reached about 28°C, earlier in winter than in the late summer. Thermal environment was assessed to be slightly less acceptable in winter only until chamber temperature reached about 28°C; acceptability systematically decreased with increasing temperature. Difficulty to concentrate increased with increased temperature and the self-estimated ability to perform work decreased; subjects reported being sleepier. Severity of headache and difficulty to concentrate was in winter slightly but systematically higher, subjects reporting also to be sleepier. Heart rate slightly increased during exposure, and SpO2 and ETCO2 began to decrease while core temperature started to increase. Performance of Tsai-partington test and addition test improved during exposures due to learning though lesser in winter. Results show negative effects of the temperature ramp, being somewhat higher in winter than in the late summer.
Socio-Economic Consequences of Improved Indoor Air Quality in Danish Primary Schools

This paper reports an attempt to estimate the socio-economic effects of upgrading the indoor air quality in Danish schools to the level of Swedish schools. The OECD “PISA” score is used to quantify the effects together with the Danish Rational Economic Agent Model (DREAM). The following effects are taken into consideration: a) increased PISA score increases productivity; b) increased PISA score reduces the duration of primary education; c) improved indoor air quality reduces absenteeism in teachers. The results show that improved air quality in Danish schools could result in an increase in the Gross Domestic Product (GDP) of €173 million per annum, and in the public finances of €37 million per annum.

The Adaptive Thermal Comfort model may not always predict thermal effects on performance

A letter to the editor is presented in response to the article "Progress in thermal comfort research over the last twenty years," by R.J. de Dear and colleagues.
The effect of air quality on sleep
The effect of air quality on sleep was examined for occupants of 14 identical single-occupancy dormitory rooms. The subjects, half women, were exposed to two conditions (open/closed window), each for one week, resulting in night-time average CO2 levels of 660 and 2585 ppm, and air temperatures of 24.7 and 23.9°C, respectively. Sleep was assessed from movement data recorded on wristwatch-type actigraphs and from online morning questionnaires, including the Groningen Sleep Quality scale, questions about the sleep environment, next-day well-being, SBS symptoms, and two tests of mental performance. Although no significant effects on the sleep quality scale or on next-day performance could be shown, there were significant and positive effects of a higher ventilation rate (open window) on the actigraph measured sleep latency and on the subjects’ assessment of the freshness of the air, their ability to fall asleep and nasal dryness. There was a negative effect on reported lip dryness.

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The effect of CO2 controlled bedroom ventilation on sleep and next-day performance
Both sleep and good indoor air quality are generally considered to be important for human health and well-being. In the present study, sleep quality and next-day performance were measured in identical single-occupancy dormitory rooms located in a quiet area North of Copenhagen. The 16 international students participating as subjects, half of them women, were sleeping in their own rooms and maintained their habitual life style, with a few restrictions on alcohol and caffeine consumption. The subjects were exposed to two conditions, each for one week, with one high and one low rate of ventilation, resulting in average CO2 levels of around 835 and 2395 ppm, respectively. A fan controlled by a CO2 sensor was used to supply outside air to establish the condition with low CO2 level. In the condition with high CO2 concentration the fan was switched off. The subjects were instructed to adjust the electric heater that was installed below the window to ensure thermal comfort and average room temperature did not differ between conditions. The indoor environment was assessed based on online morning questionnaires and physical measurements of room air temperature, relative humidity and CO2 concentration. The subjects’ sleep quality and next-day performance were assessed from subjective responses that were obtained by using visual analogue scales and the Groningen Sleep Quality scale, from one test of logical thinking, one diagnostic test of cue-utilisation, and in terms of movement data recorded on wristwatch-type actigraphs.

The results show positive effects of a higher ventilation rate on the subjectively assessed freshness of the air, on the subjects’ mental state and their feeling of being rested. There was also a significant and positive effect on the sleep efficiency measured by the actigraphs and the expected significant and positive effect on performance. However, there were some negative effects of the higher ventilation rate on the rated intensity of mouth dryness and skin dryness.

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Organisations: Department of Civil Engineering, Section for Indoor Environment, Section for Building Physics and Services
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Thermal effects on human performance in office environment measured by integrating task speed and accuracy

We have proposed a method in which the speed and accuracy can be integrated into one metric of human performance. This was achieved by designing a performance task in which the subjects receive feedback on their performance by informing them whether they have committed errors, and if so, they can only proceed when the errors are corrected. Traditionally, the tasks are presented without giving this feedback and thus the speed and accuracy are treated separately. The method was examined in a subjective experiment with thermal environment as the prototypical example. During exposure in an office, 12 subjects performed tasks under two thermal conditions (neutral & warm) repeatedly. The tasks were presented with and without feedback on errors committed, as outlined above. The results indicate that there was a greater decrease in task performance due to thermal discomfort when feedback was given, compared to the performance of tasks presented without feedback.

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Ventilation System Type and the Resulting Classroom Temperature and Air Quality During Heating Season

The present study investigated how different ventilation system types influence classroom temperature and air quality. Five classrooms were selected in the same school. They were ventilated by manually operable windows, manually operable windows with exhaust fan, automatically operable windows with and without exhaust fan and by mechanical ventilation system. Temperature, relative humidity, carbon dioxide (CO₂) concentration and opening of windows were continuously monitored for one month during heating season in 2012. Classroom with manually operable windows had the highest carbon dioxide concentration levels so that the estimated ventilation rate was the lowest compared with the classrooms ventilated with other systems. Temperatures were slightly lower in classroom ventilated by manually operable windows with exhaust fan. Windows were opened seldom even in the classroom ventilated by manually operable windows. Classrooms with automatically operable windows and exhaust fan and with mechanical ventilation systems achieved the best thermal environment and air quality during heating season among all classrooms examined.

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Contributors: Gao, J., Wargocki, P., Wang, Y.
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Ventilation system type, classroom environmental quality and pupils’ perceptions and symptoms

The present study investigated indoor climate and window opening behaviour by pupils, as well as their perceptions and symptoms in classrooms with different types of ventilation systems. Four classrooms were selected in the same school in suburban Denmark. Classroom ventilation was achieved either by manually operable windows, or by automatically operable windows with and without an exhaust fan in operation, or by a balanced mechanical ventilation system. Indoor air temperature, relative humidity, carbon dioxide (CO₂) concentration and window opening were continuously monitored for one month in non-heating and heating seasons; CO₂ concentration was used to estimate average classroom ventilation rates. At the end of each measuring period, the pupils were asked to report their perceptions of the indoor environment and their acute health-related symptoms. The classroom in which ventilation was achieved by manually operable windows had the highest air temperatures and CO₂ concentrations during both non-heating and heating season; the estimated average air-change rate was lowest in this classroom. The classroom with mechanical ventilation had the highest estimated average air-change rate. Windows were frequently opened in all four classrooms in the non-heating season but very seldom in the heating season. Automatic operation of the windows had a marked effect on CO₂ concentration and classroom temperature in the heating season. Perceptions of the indoor environment were more positive in the classroom that was ventilated by automatically operable windows with an exhaust fan in operation: fewer symptoms were reported in this classroom compared with classrooms with other systems. Present results and approach can be used as the basis for rational selection of systems that ensure adequate classroom ventilation. © 2014 Elsevier Ltd.

Waste-based materials; capability, application and impact on indoor environment – literature review

This paper reviews and discusses various sustainable materials utilizing waste products with the focus on their properties having an impact on the indoor environmental conditions and indoor air quality (IAQ). Materials included in the review are selected considering the following aspects: sustainability, cradle to cradle perspective, application, their impact on indoor environment and human well-being. The attempt of the paper is to cover a wide spectrum of information so to provide better understanding of waste utilization in construction industry.
ZeroWaste BYG: Hygro-thermal conditions and pollutant emissions from ZeroWaste materials and their effects on humans

The ZeroWaste research group (www.zerowaste.byg.dtu.dk) at the Department of Civil Engineering was established in 2012 and covers the broad range of expertise required for turning waste materials into attractive, new materials. Members of the group have developed methods for removal of heavy metals and phosphorous from waste incineration, sewage sludge and other bio ashes [1], providing the basis to make these ash types an attractive, new material for the building sector. The amount of waste increases and it is both difficult and expensive to handle many waste types as e.g. different ashes. At the same time there are fewer natural resources and the general consumption increases. We wish to utilize alternative and new ash types as raw material in concrete, similarly to what was previously seen with fly ash from coal combustion and microsilica, which were both transformed from problematic waste to valuable raw material. The physical-chemical characteristics of fly ash, such as large uniformity coefficient, clay-sized particles and rich in some metal elements and salts, show the possibility of being a raw material also for bricks and lightweight aggregates. In the future we expect increasing political pressure to change the status of different ashes from waste to raw material and that export for disposal will be no longer be allowed. We wish to influence the consequences from this new situation. In principle some of the ashes can be used already, but the huge variation in ash characteristics and lack of knowledge in the construction industry on the qualities some of the ashes can give the concrete and clay materials means that they are not used today.

ZeroWaste BYG: Redesigning construction materials towards zero waste society

The ZeroWaste research group (www.zerowaste.byg.dtu.dk) at the Department of Civil Engineering was established in 2012 and covers the broad range of expertise required for turning waste materials into attractive, new materials. Members of the group have developed methods for removal of heavy metals and phosphorous from waste incineration, sewage sludge and other bio ashes [1], providing the basis to make these ash types an attractive, new material for the building sector. The amount of waste increases and it is both difficult and expensive to handle many waste types as e.g. different ashes. At the same time there are fewer natural resources and the general consumption increases. We wish to utilize alternative and new ash types as raw material in concrete, similarly to what was previously seen with fly ash from coal combustion and microsilica, which were both transformed from problematic waste to valuable raw material. The physical-chemical characteristics of fly ash, such as large uniformity coefficient, clay-sized particles and rich in some metal elements and salts, show the possibility of being a raw material also for bricks and lightweight aggregates. In the future we expect increasing political pressure to change the status of different ashes from waste to raw material and that export for disposal will be no longer be allowed. We wish to influence the consequences from this new situation. In principle some of the ashes can be used already, but the huge variation in ash characteristics and lack of knowledge in the construction industry on the qualities some of the ashes can give the concrete and clay materials means that they are not used today.
How indoor environment affects performance
As experienced researchers in the effects of thermal comfort and indoor air quality on performance, we are often asked to give our best estimate of how, and to what extent, performance is affected by different aspects of indoor climate. This article provides a brief summary of our personal opinions, in the form of answers to 40 frequently asked questions. Our answers are based on the results of behavioral experiments conducted to date. We offer no opinions on long-term health effects of indoor environmental quality. We provide some references to relevant sources, but there is not enough space for all such references. We list some questions we cannot answer as topics for future research in this area.

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Providing better thermal and air quality conditions in school classrooms would be cost-effective
This paper is an overall summary of research by the authors on how classroom conditions affect the performance of schoolwork by children, motivated by the fact that the thermal and air quality conditions in school classrooms are now almost universally worse than the relevant standards and building codes stipulate that they should be. This is sometimes because financial resources for the maintenance and upgrade of school buildings are inadequate, but it is also because schools are increasingly allowing classroom temperatures to drift above the recommended range of 20–22 °C in warm weather and allowing outdoor air supply rates to remain so low that carbon dioxide (CO2) levels during school hours exceed 1000 ppm for long periods, in order to conserve energy. The research that is summarized in this paper shows that the indoor environmental consequences of either of these investment-free but ill-advised energy conservation measures can reduce children’s performance of schoolwork by as much as 30%, so a more sophisticated approach to maintaining good classroom indoor environmental quality (IEQ) is required.

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Standards for securing adequate indoor air quality across Europe: setting the scene for health based ventilation guidelines proposed by the HealthVent project

Background: Inadequate IAQ causes a loss of 2 million healthy life years annually in the EU. Europeans spend typically over 85–90% of their time indoors and the main factors that affect negatively the characteristics of the air they breathe are outdoor air used to ventilate indoor spaces and indoor sources of pollution. Ventilation is one of many factors determining IAQ. The aim of DG SANCO funded HealthVent project was to assess how ventilation should be defined in terms of achieving conditions for securing health.

Methods: Review of the available literature was made so as to break down the health effects of IAQ into different components: exposures to indoor and outdoor air pollutants, association with different morbidities and the way ventilation based approaches could minimise their impact. Disability adjusted life years (DALYs), a common metric to allow comparability of impacts on various types of diseases and mortality was used in risk analysis. Ventilation rate was defined as volume of fresh air introduced into the space per person (L/sp).

Results: The data in the reviewed studies on ventilation and health were found inadequate to set the health-based ventilation rates mainly because the studies improperly characterised exposures and because of their inhomogeneity. Risk modelling simulations of different strategies resulting in reduction of DALYs suggested that health-based ventilation requirements should be combined with source control strategies and if necessary cleaning of outdoor air in order to be efficient. As a consequence HealthVent proposed that source control is a key strategy for IAQ and that ventilation should be an ultimate measure. HealthVent defined the minimum reference ventilation rate to reduce risk of health to be set at 4 L/s per person. This rate is only to handle human bioeffluents and is determined mainly considering the metabolic CO2 production. It is only applicable if all other pollutants meet WHO guidelines for ambient and indoor air quality. If they do not meet these guidelines after applying source control and when air used for ventilation is clean health-based ventilation rate should be a multiple of the minimum rate.

Conclusions: Optimal strategy for ensuring adequate IAQ to ensure health conditions must include cleaning of ambient air (if necessary) and source control; only then health-based ventilation rate can be defined. Such approach is expected to half the BOD caused by indoor exposures.
The Effects of Ventilation in Homes on Health

It is estimated that people in the developed world spend more than 85-90% of their time indoors. Of this, most is spent in homes. To minimize health risks from pollutants occurring in homes, exposures should be controlled. The most effective way to achieve this is to control sources of pollutants and to reduce emissions. Often, especially in existing buildings, this strategy is difficult to implement, in which case exposures are controlled by providing sufficient, presumably clean, outdoor ventilation air to dilute and remove the contaminants. The present paper attempts to find out how much ventilation is needed in existing homes to reduce health risks. This is achieved by reviewing the published scientific literature investigating the association between measured ventilation rates and the measured and observed health problems. The paper concludes that, generally, there are very few studies on this issue and many of them suffer from deficient experimental design, as well as a lack of proper characterization of actual exposures occurring indoors. Based on the available data, in the reviewed studies, it seems likely that health risks may occur when ventilation rates are below 0.4 air changes per hour in existing homes. No data were found indicating that buildings having dedicated natural ventilation systems perform less well than the dwellings in which mechanical ventilation systems are installed. Newly installed mechanical ventilation systems were observed to improve health conditions. In homes with existing ventilation systems this positive effect was less evident, probably due to poor performance of the system (too low ventilation rates and/or poor maintenance). Studies are recommended in which exposures are much better characterized (by for example measuring the pollutants indicated by the WHO Guidelines for Indoor Air Quality and improving ventilation measurements). Exposures should also be controlled using different ventilation methods for comparison. Future studies should also advance the understanding of how ventilation systems should be operated to achieve optimal performance. These data would create further input and support to the guidelines for ventilation based on health developed currently in the framework of the HealthVent project (www.healthvent.eu).
Warmth and performance: reply to the letter from Leyten and Kurvers (2013)

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Impacts of a clay plaster on indoor air quality assessed using chemical and sensory measurements
Passive removal materials (PRMs) are building materials or furnishings that effectively control indoor pollution without substantial formation of chemical byproducts and without an energy penalty. Recent studies have suggested that clay might be an effective PRM for ozone. To assess clay wall plaster as a PRM for improving air quality by controlling ozone, perceived air quality (PAQ) was determined in the presence of eight combinations of an emitting and reactive pollutant source (new carpet), clay plaster applied to gypsum wallboard, and chamber air with and without ozone. A panel of 24 human subjects assessed air quality in twin 30m³ chambers using a continuous acceptability scale. Air samples were collected immediately prior to panel assessment to quantify concentrations of C₅–C₁₀ saturated n-aldehydes and two aromatic aldehydes that are commonly produced by reaction of ozone with carpet. Perceived air quality was most acceptable and concentrations of aldehydes were lowest when only clay plaster or both clay plaster and carpet were present in the chambers without ozone. The least acceptable PAQ and the highest concentrations of aldehydes were observed when carpet and ozone were present together; addition of clay plaster for this condition improved PAQ and considerably decreased aldehyde concentrations.

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Organisations: Department of Civil Engineering, Section for Indoor Environment, University of Texas, Missouri University of Science and Technology
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BFI (2012): BFI-level 1
Model-based approach to account for the variation of primary VOC emissions over time in the identification of indoor VOC sources

The study objectives were to improve the understanding of the long-term variation of VOC emission chromatograms of building materials and to develop a method to account for this variation in the identification of individual sources of VOC emissions. This is of importance for the application of the source identification method since materials age over time in real indoor environments. The method is based on the mixed air sample measurements containing pollutants from multiple aged materials and the emission signatures of individual new materials determined by PTR-MS. Three emission decay source models were employed and evaluated for their ability to track the change of individual material emission signatures by PTR-MS over a nine-month period. Nine building material specimens were studied in a ventilated 50-L small-size chamber for their emissions individually for nine months, and also in combination later. Chamber exhaust air was sampled by PTR-MS to construct a temporal profile of emission signature unique to individual product type. The similar process was taken to measure mixture emissions from multiple materials, which is for applying and validating the developed method for source identification enhancement, considering the variation in long-term emission rates of individual VOCs. Results showed that the proposed approach could predict the emission signatures of individual building materials at a later time (9-month) with less than 6% difference variance, and hence indicated the potential of the source identification method for aged materials in real indoor environments.

Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design

The article examines which subjectively evaluated indoor environmental parameters and building features mostly affect occupants' satisfaction in mainly US office buildings. The study analyzed data from a web-based survey administered to 52,980 occupants in 351 office buildings over 10 years by the Center for the Built Environment. The survey uses 7-point ordered scale questions pertaining to satisfaction with indoor environmental parameters, workspace, and building features. The average building occupant was satisfied with
his/her workspace and building. Proportional odds ordinal logistic regression shows that satisfaction with all 15 parameters listed in the survey contributed significantly to overall workspace satisfaction. The most important parameters were satisfaction with amount of space (odds ratio OR 1.57, 95% CI: 1.55–1.59), noise level (OR 1.27, 95% CI: 1.25–1.29), and visual privacy (OR 1.26, 95% CI: 1.24–1.28). Satisfaction with amount of space was ranked to be most important for workspace satisfaction, regardless of age group (below 30, 31–50 or over 50 years old), gender, type of office (single or shared offices, or cubicles), distance of workspace from a window (within 4.6 m or further), or satisfaction level with workspace (satisfied or dissatisfied). Satisfaction with amount of space was not related to the gross amount of space available per person.

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Questionnaire survey on factors influencing comfort with indoor environmental quality in Danish housing
A questionnaire survey in Danish homes investigated the factors that influence occupants' comfort. The questionnaire contained questions on inhabitants' behaviour, their knowledge as regards building systems designed for controlling the indoor environment and the ways in which they achieve comfort. A total of 2499 questionnaires were sent to inhabitants of the most common types of housing in Denmark; 645 persons replied (response rate of 26%). The results show that the main indoor environmental parameters (visual, acoustic and thermal conditions, and air quality) are considered by occupants to be the most important parameters determining comfort. Manual control of the indoor environment was indicated by the respondents as highly preferred, and only in the case of temperature did they accept both manual and automatic control. The respondents indicated that they were confident about how the systems for controlling indoor environmental quality in their homes should be used. 54% of them reported to have had at least one problem related to the indoor environment at home. A majority of those respondents did not try to search for information on how to solve the problem. This may suggest that there is a need for increasing people's awareness regarding the consequences of a poor indoor environment on their health and for improving people's knowledge on how to ensure a good indoor climate.

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Satisfaction and self-estimated performance in relation to indoor environmental parameters and building features

The paper examines how satisfaction with indoor environmental parameters and building features affects satisfaction and self-estimated job performance. The analyses used subjective responses from around 50,000 occupants collected mainly in US office buildings using a web-based survey administered by the Center for the Built Environment (CBE) over the period of ten years. Overall satisfaction with the workspace significantly improved self-estimated job performance; increased satisfaction with temperature was estimated to provide the greatest improvement in self-estimated job performance, followed by increase in satisfaction with noise and air quality. The improvement of building features such as amount of space, visual privacy and noise level offered the highest chance to improve satisfaction with workspace. The study implies that it should be carefully considered how investments to upgrade indoor environmental quality and building design are used, and that they should consider whether comfort or working morale are expected to be improved.

Use of CO₂ feedback as a retrofit solution for improving air quality in naturally ventilated classrooms

Carbon dioxide (CO₂) sensors that provide a green/yellow/red visual indication were installed in pairs of naturally ventilated classrooms during normal school operation. During a two-week period in the heating and the cooling season, teachers and students were instructed to open the windows in response to the CO₂ feedback in one week and open them as they would normally do, without feedback, in the other week. In the cooling season, two pairs of classrooms were monitored, one pair with split cooling in operation and the other pair with no cooling. The resulting indoor environmental conditions in these classrooms and window opening behaviour were monitored. Children also reported their perceptions and symptoms. Resulting energy use was measured and used to estimate annual energy use. Providing CO₂ feedback reduced CO₂ levels. More windows were opened in this condition, and this increased energy use for heating and reduced the cooling requirement. Split-cooling reduced the frequency of window opening when no CO₂ feedback was present, suggesting that classroom temperature is the driving factor for this behavioural response. Children liked CO₂ feedback; their perceptions and symptoms were somewhat improved with CO₂ feedback, although many of these changes did not reach formal statistical significance.
Can commonly-used fan-driven air cleaning technologies improve indoor air quality? A literature review

Air cleaning techniques have been applied worldwide with the goal of improving indoor air quality. The effectiveness of applying these techniques varies widely, and pollutant removal efficiency is usually determined in controlled laboratory environments which may not be realized in practice. Some air cleaners are largely ineffective, and some produce harmful by-products. To summarize what is known regarding the effectiveness of fan-driven air cleaning technologies, a state-of-the-art review of the scientific literature was undertaken by a multidisciplinary panel of experts from Europe, North America, and Asia with expertise in air cleaning, aerosol science, medicine, chemistry and ventilation. The effects on health were not examined. Over 26,000 articles were identified in major literature databases; 400 were selected as being relevant based on their titles and abstracts by the first two authors, who further reduced the number of articles to 160 based on the full texts. These articles were reviewed by the panel using predefined inclusion criteria during their first meeting. Additions were also made by the panel. Of these, 133 articles were finally selected for detailed review. Each article was assessed independently by two members of the panel and then judged by the entire panel during a consensus meeting. During this process 59 articles were deemed conclusive and their results were used for final reporting at their second meeting. The conclusions are that: (1) None of the reviewed technologies was able to effectively remove all indoor pollutants and many were found to generate undesirable by-products during operation. (2) Particle filtration and sorption of gaseous pollutants were among the most effective air cleaning technologies, but there is insufficient information regarding long-term performance and proper maintenance. (3) The existing data make it difficult to extract information such as Clean Air Delivery Rate (CADR), which represents a common benchmark for comparing the performance of different air cleaning technologies. (4) To compare and select suitable indoor air cleaning devices, a labeling system accounting for characteristics such as CADR, energy consumption, volume, harmful by-products, and life span is necessary. For that purpose, a standard test room and condition should be built and studied. (5) Although there is evidence that some air cleaning technologies improve indoor air quality, further research is needed before any of them can be confidently recommended for use in indoor environments.

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Consideration Of The Change Of Material Emission Signatures Due To Long-term Emissions For Enhancing Voc Source Identification

The objectives of this study were to characterize the changes of VOC material emission profiles over time and develop a method to account for such changes in order to enhance a source identification technique that is based on the measurements of mixed air samples and the emission signatures of individual building materials determined by PTRMS. Source models, including powerlaw model, doubleexponential decay model and mechanistic diffusion model, were employed to track the change of individual material emission signatures by PTRMS over a ninemonth period. Samples of nine typical building materials were tested individually for nine months and later in combination to obtain actual mixture emissions. VOC emissions from each material were measured in a 50liter smallscale chamber. Chamber air was sampled by PTRMS over a 28day period to determine their emission rate decay characteristics as well as to establish the initial profile of emission signatures unique to individual materials tested.

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Development of a novel methodology for indoor emission source identification

The objective of this study was to develop and evaluate a methodology to identify individual sources of emissions based on the measurements of mixed air samples and the emission signatures of individual materials previously determined by Proton Transfer Reaction-Mass Spectrometry (PTR-MS), an on-line analytical device. The methodology based on signal processing principles was developed by employing the method of multiple regression least squares (MRLS) and a normalization technique. Samples of nine typical building materials were tested individually and in combination, including carpet, ceiling material, gypsum board, linoleum, two paints, polyolefine, PVC and wood. Volatile Organic Compound (VOC) emissions from each material were measured in a 50-liter small-scale chamber. Chamber air was sampled by PTR-MS to establish a database of emission signatures unique to each individual material. The same task was performed to measure combined emissions from material mixtures for the application and validation of the developed signal separation method. Results showed that the proposed method could identify the individual sources under laboratory conditions with two, three, five and seven materials present. Further experiments and investigation are needed for cases where the relative emission rates among different compounds may change over a long-term period.

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Effect of streamer plasma air purifier on SBS symptoms and performance of office work

Subjective experiments were conducted to evaluate the effect of a streamer plasma air purifier on perceived air quality, SBS symptoms and performance of office work during 5-hour exposure of 32 recruited subjects in field laboratory in which real materials were used to establishing a realistic level of air pollution. Intensity of SBS symptoms were indicated using visual-analogue scales. Subjects’ performance was evaluated with several computer tasks. The results show that operation of the air purifiers improved perceived air quality and reduced the odor intensity of indoor air. Eye dryness symptom was found significantly improved when the air purifiers were used but no other SBS symptoms or performance of office work were improved when the air purifiers were in operation compared to the condition when they were off.

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Keywords: Indoor air quality, Air cleaning, Perceived air quality, SBS symptoms and productivity
Electronic versions:
EFFECT OF STREAMER PLASMA.pdf
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Source-ID: 316355

Effects of thermal discomfort in an office on perceived air quality, SBS symptoms, physiological responses and human performance

The effects of thermal discomfort on health and human performance were investigated in an office, in an attempt to elucidate the physiological mechanisms involved. Twelve subjects (six men and six women) performed neurobehavioral tests and tasks typical of office work while thermally neutral (at 22°C) and while warm (at 30°C). Multiple physiological measurements and subjective assessment were made. The results show that when the subjects felt warm, they assessed the air quality to be worse, reported increased intensity of many sick building syndrome symptoms, expressed more negative mood, and were less willing to exert effort. Task performance decreased when the subjects felt warm. Their heart rate, respiratory ventilation, and end-tidal partial pressure of carbon dioxide increased significantly, and their arterial oxygen saturation decreased. Tear film quality was found to be significantly reduced at the higher temperature when they felt warm. No effects were observed on salivary biomarkers (alpha-amylase and cortisol). The present results imply that the negative effects on health and performance that occur when people feel thermally warm at raised temperatures are caused by physiological mechanisms.

General information
Publication status: Published
Organisations: Section for Indoor Environment, Department of Civil Engineering, Shanghai Jiao Tong University
Contributors: Lan, L., Wargocki, P., Wyon, D. P., Liam, Z.
Publication date: 2011
Peer-reviewed: Yes

Publication information
Journal: Indoor Air
ISSN (Print): 0905-6947
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BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 2.42
Hvad koster et godt indeklima på folkeskoler?

General information
Publication status: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, Section for Indoor Environment
Contributors: Marxen, C., Knorborg, R. B., Hviid, C. A., Wargocki, P.
Pages: 40,42,44,49
Publication date: 2011
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Journal: H V A C Magasinet
Issue number: 9
ISSN (Print): 1603-6913
Original language: Danish
URLs:
http://techmedia.swiflet.com/tm/hvac/59/1/
Source: orbit
Source-ID: 316328
Research output: Contribution to journal › Journal article – Annual report year: 2011 › Communication

Impacts Of Passive Removal Materials On Indoor Air Quality
Indoor air quality (IAQ) was determined in the presence of eight combinations of building materials with and without ozone. Air samples were collected in twin 30 m3 chambers to assess the C5 to C10 aldehyde content of the air while a panel of 18 to 23 human subjects assessed air quality using a continuous acceptability scale. Materials were either new carpet that was aired out for three weeks, clay plaster applied to gypsum wallboard that was aired out for up to one month, both materials, or neither. Perceived Air Quality (PAQ) assessed by the panel was most acceptable and concentrations of aldehydes were lowest when only clay plaster or both clay plaster and carpet were in the chambers without ozone. The least acceptable PAQ and the highest concentrations of aldehydes were observed when carpet and ozone were present together; addition of clay plaster for this condition improved PAQ and considerably decreased aldehyde concentrations.

General information
Publication status: Published
Organisations: Section for Indoor Environment, Department of Civil Engineering, University of Texas, Technical University of Denmark, Missouri University of Science and Technology
Contributors: Darling, E., Cros, C., Wargocki, P., Kolarik, J., Targowski, A., Morrison, G. C., Corsi, R. L.
Publication date: 2011

Host publication information
Title of host publication: Indoor Air 2011
URLs:
http://lifelong.engr.utexas.edu/2011/
Source: orbit
Source-ID: 275611
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2011 › Research › peer-review

Indeklima i skoler – Status og konsekvenser

General information
Indoor Climate Quality Assessment: Evaluation of indoor thermal and indoor air quality
This Guidebook gives building professionals useful support in the practical measurements and monitoring of the indoor climate in buildings. It is evident that energy consumption in a building is directly influenced by required and maintained indoor comfort level. Wireless technologies for measurement and monitoring have allowed a significantly increased number of possible applications, especially in existing buildings. The Guidebook illustrates several cases with the instrumentation of the monitoring and assessment of indoor climate.

Literature survey on how different factors influence human comfort in indoor environments
The present paper shows the results of a literature survey aimed at exploring how the indoor environment in buildings affects human comfort. The survey was made to gather data that can be useful when new concepts of controlling the indoor environment are developed. The following indoor environmental conditions influencing comfort in the built environment were surveyed: thermal, visual and acoustic, as well as air quality. The literature was surveyed to determine which of these conditions were ranked by building users as being the most important determinants of comfort. The survey also examined the extent to which other factors unrelated to the indoor environment, such as individual characteristics of building occupants, building-related factors and outdoor climate including seasonal changes, influence whether the indoor environment is evaluated as comfortable or not. The results suggest that when developing systems for controlling the indoor environment, the type of building and outdoor climate, including season, should be taken into account. Providing occupants with the possibility to control the indoor environment improves thermal and visual comfort as well as satisfaction with the air quality. Thermal comfort is ranked by building occupants to be of greater importance compared with visual and acoustic comfort and good air quality. It also seems to influence to a higher degree the overall satisfaction with indoor environmental quality compared with the impact of other indoor environmental conditions.
Measure the effects of thermal discomfort on the performance of office work

Accuracy and speed are the two distinct aspects of human performance. A method was proposed by which the speed and accuracy were integrated into one measure by designing the tasks in such a way that the participants can only proceed to the next test when the task was performed without errors. The method was examined through a subjective experiment with thermal environment as the prototypical example. The experimental results indicate that the negative effects of thermal discomfort on human performance were evaluated well by the tasks designed with the proposed method. It provides a useful tool for better measurement of human performance and helps to facilitate the development of quantitative relationship between IEQ and productivity.

General information

Publication status: Published
Organisations: Department of Civil Engineering, Section for Indoor Environment, Shanghai Jiao Tong University
Contributors: Lan, L., Wargocki, P., Lian, Z.
Pages: 358-362
Publication date: 2011

Host publication information

Title of host publication: 7th International Symposium on Heating, Ventilating and Air Conditioning - Proceedings of ISHVAC 2011
Volume: 2
Publisher: Secretariat of ISHVAC2011
ISBN (Print): 9789628513802
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Source-ID: n:oat:DTIC-ART:compendex/370521243::19868

Performance of a Streamer Plasma Air Purifier Examined with Sensory Assessments of Air Quality

General information

Publication status: Published
Organisations: Section for Indoor Environment, Department of Civil Engineering
Contributors: Fang, L., Wargocki, P., Targowski, A., Tanaka, T., Kagawa, K.
Publication date: 2011

Host publication information

Title of host publication: Proceedings of Indoor Air 2011 : Austin, Texas, USA
URLs:
http://lifelong.engr.utexas.edu/2011/
Source: orbit
Source-ID: 275466

Productivity and Health Effects of High Indoor Air Quality
Quantitative measurement of productivity loss due to thermal discomfort

The effects on human performance of elevated temperature causing thermal discomfort were investigated. Recruited subjects performed neurobehavioural tests examining different component skills, and addition and typing tasks that were used to replicate office work. The results show that thermal discomfort caused by elevated air temperature had a negative effect on performance. A quantitative relationship was established between thermal sensation votes and task performance. It can be used for economic calculations pertaining to building design and operation when occupant productivity is considered. The relationship indicates that optimum performance can be achieved slightly below neutral, while thermal discomfort (feeling too warm or too cold) leads to reduced performance. Consequently, it makes sense to set the PMV limits in workplaces in the range between −0.5 and 0 instead of between −0.5 and 0.5 as stipulated in the present standards.

Quantitative relationships between occupant satisfaction and aspects of indoor environmental quality and building design

The paper examines which indoor environmental parameters and building features contribute occupants' satisfaction in office buildings. The study analyzed data from a web-based survey administered to 52,980 occupants in 351 office buildings over ten years at the Center for the Built Environment. The survey uses 7-point scale questioning satisfaction with parameters related to the indoor environment, workspace and building features. Building occupants were generally satisfied with their workspaces and their buildings. Proportional odds ordinal logistic regression showed that satisfaction with all parameters listed in the survey contributed to overall workspace satisfaction. The most important parameters were: satisfaction with amount of space (odds ratio OR 1.57), noise (OR 1.27) and visual privacy (OR 1.26). Satisfaction with amount of space was not noticeably affected by size of workspace, and improved by having a private office and sitting
Can a photocatalytic air purifier be used to improve the perceived air quality indoors?

The effect of a photocatalytic air purifier on perceived air quality (PAQ) was examined in rooms polluted by typical sources of indoor pollution. The rooms were ventilated at three different outdoor air supply rates. The air quality was assessed by a sensory panel when the purifier was in operation as well as when it was off. Operation of the purifier significantly improved PAQ in the rooms polluted by building materials (used carpet, old linoleum, and old chip-board), and a used ventilation filter as well as a mixture of building materials, used ventilation filter and cathode-ray tube computer monitors. The effect corresponded to approximately doubling the outdoor air supply rate. Operation of the purifier significantly worsened the PAQ in rooms with human bioeffluents, probably due to incomplete oxidation of alcohols which are one of the main pollutants emitted by humans. Present results show that the photocatalytic air purifier can supplement ventilation when the indoor air is polluted by building-related sources, but should not be used in spaces where human bioeffluents constitute the main source of pollution.

Classroom ventilation must be improved for better health and learning

The effect of improving classroom ventilation on perceived air quality (PAQ) was investigated in a school environment. The rooms were ventilated at different outdoor air supply rates. The air quality was assessed by a sensory panel when the ventilation system was in operation as well as when it was off. Improvement of ventilation significantly improved PAQ. However, it was found that even with improved ventilation, PAQ could still be significantly affected by human bioeffluents emitted by students. This highlights the importance of considering both ventilation and human bioeffluents in the design of effective classroom environments.
Determination of material emission signatures by PTR-MS and their correlations with odor assessments by human subjects

The objectives of this study were to determine volatile organic compound (VOC) emission signatures of nine typical building materials by using proton transfer reaction-mass spectrometry (PTR-MS) and to explore the correlation between the PTR-MS measurements and the measurements of acceptability by human subjects. VOC emissions from each material were measured in a 50-l small-scale chamber. Chamber air was sampled by PTR-MS to determine emission signatures. Sorbent tube sampling and TD-GC/MS analysis were also performed to identify the major VOCs emitted and to compare the resulting data with the PTR-MS emission signatures. The data on the acceptability of air quality assessed by human subjects were obtained from a previous experimental study in which the emissions from the same batch of materials were determined under the same area-specific ventilation rates as in the case of the measurements with PTR-MS. Results show that PTR-MS can be an effective tool for establishing VOC emission signatures of material types and that there were reasonable correlations between the PTR-MS measurements and the acceptability of air quality for the nine materials tested when the sum of selected major individual VOC odor indices was used to represent the emission level measured by PTR-MS.
How one should perform sensory measurements of perceived air quality
The purpose of the present experiment was to study different aspects of sensory evaluations of air quality made by human subjects. The sensory panel of 40 subjects assessed the quality of the air polluted by 6 different building materials commonly used indoors. Both low- and high polluting materials were chosen for the study, including carpet, linoleum, PVC, ceiling and two different paints. The assessments were performed in the small-scale in 20 glass chambers called CLIMPAQs. Each CLIMPAQ was loaded with single material. Each material was examined at three different area specific ventilation rates, obtained by changing the material loading and keeping the airflow through CLIMPAQ at 0.9 L/s unchanged. Different scales and procedures of the sensory evaluation were used while performing the experiment. The results show that: 1. There were no differences between sensory ratings taken after 1 inhalation or 3 inhalations of air extracted from the chambers; 2. There were no differences between sensory ratings whether the materials in the chamber were visible or not visible to subjects; 3. There were no differences in sensory assessments taken with 3-minute break between assessments and with 3 inhalations of unpolluted air between assessments; and 4. There were no changes in the sensory assessments of the same exposure during the 3-week of experiments. The relationship between acceptability and the percentage of dissatisfied with the air quality as well as odor intensity and the percentage of dissatisfied with air quality. They were developed using independent assessments on the continuous acceptability scale and category intensity scale, as well as dichotomous (yes/no) acceptability scale; the ratings on the latter were used to estimate the percentage of dissatisfied. These relationships can be used when ventilation requirements are set in indoor environments.

General information
Publication status: Published
Organisations: Section for Indoor Environment, Department of Civil Engineering, Aalborg University, Technical University of Denmark
Contributors: Wargocki, P., Knudsen, H. N., Krzyzanowska, J.
Pages: R7-TS15-OP05
Publication date: 2010

Strategy for good perceived air quality in sustainable buildings
Source control has been shown to be an effective strategy for improving air quality. The objective of the present study was to investigate and compare the potential for achieving an improved perceived indoor air quality by selecting less-polluting building materials or by increasing the ventilation rate in real rooms. Relationships between ventilation rate and perceived indoor air quality were established for differently polluting materials in real rooms. The results showed that the use of low-polluting materials reduced the ventilation rate required to achieve an acceptable level of perceived air quality and thereby prevented unnecessary use of energy for ventilation. For some high-polluting materials it will not be realistic in practice to provide enough ventilation to achieve an acceptable level of perceived air quality. Therefore, the use of low-polluting materials should be part of a strategy for good perceived air quality in sustainable buildings.

General information
Publication status: Published
Organisations: Section for Indoor Environment, Department of Civil Engineering, Aalborg University
Contributors: Knudsen, H. N., Wargocki, P.
Pages: R7-TS7-OP03
Publication date: 2010

The effect of a photocatalytic air purifier on indoor air quality quantified using different measuring methods
The effect on indoor air quality of an air purifier based on photocatalytic oxidation (PCO) was determined by different measuring techniques: sensory assessments of air quality made by human subjects, Proton-Transfer-Reaction Mass Spectrometry (PTR-MS) and chromatographic methods (Gas Chromatography/Mass Spectrometry and High-Pressure Liquid Chromatography with UV detection). The experiment was conducted in a simulated office, ventilated with 0.6 h(-1), 2.5 h(-1) and 6 h(-1), in the presence of additional pollution sources (carpet, chipboard and linoleum). At the lowest air
change rate, additional measurements were made with no pollution sources present in the office. All conditions were tested with the photocatalytic air purifier turned on and off. The results show that operation of the air purifier in the presence of pollutants emitted by building materials and furniture improves indoor air quality, as documented by sensory assessments made by human subjects. It also reduces concentrations of many chemical compounds present in the air as documented by the PTR-MS technique. For the lowest ventilation, results from measurements using the chromatographic methods have similar tendency, however many of the 50 compounds that were targeted for analysis were not detected at all, independent of whether the purifier was on or off. For the two conditions with higher ventilation the results were inconclusive.

The effects of non-environmental factors on comfort, a literature survey

Analiza zużycia energii na potrzeby wentylacji i klimatyzacji dzięki zastosowaniu materiałów budowlanych i wyposażenia o niskiej emisji zanieczyszczeń powietrza
Improving indoor air quality improves the performance of officework and school work
Indoor climate and productivity in offices. How to integrate productivity in life cycle costs analysis of building services

Material labelling: Combined material emission tests and sensory evaluations

Measuring perceived air quality and intensity by a Sensor System, the European Project SysPAQ
Proceedings of Indoor Air 2008, the 11th International Conference on Indoor Air Quality and Climate

General information
Publication status: Published
Organisations: Section for Indoor Environment, Department of Civil Engineering
Contributors: Strøm-Tejsen, P., Olesen, B. W., Wargocki, P., Zukowska, D., Toftum, J.
Publication date: 2008

Publication information
Place of publication: Copenhagen, Denmark
Publisher: Proceedings on CDRange
Original language: English
Source: orbit
Source-ID: 233860
Research output: Book/Report → Book – Annual report year: 2008 → Research → peer-review

Results of the recent Indoor Air 2008 conference: Productivity and schools

General information
Publication status: Published
Organisations: Section for Indoor Environment, Department of Civil Engineering
Contributors: Wargocki, P.
Publication date: 2008
Peer-reviewed: No

Publication information
Journal: REHVA Journal
Issue number: September, 11-13
ISSN (Print): 1307-3729
Original language: English
Source: orbit
Source-ID: 233865
Research output: Contribution to journal → Journal article – Annual report year: 2008 → Research

Saving energy for ventilation by careful selection of building materials

General information
Publication status: Published
Organisations: Section for Indoor Environment, Department of Civil Engineering
Contributors: Wargocki, P., Knudsen, H.
Pages: 489-496
Publication date: 2008

Host publication information
Title of host publication: Nordic Symposium on Building Physics : Proceedings
Volume: 1
Publisher: Technical University of Denmark (DTU)
Editor: Rode, C.
Source: orbit
Source-ID: 233800
Research output: Chapter in Book/Report/Conference proceeding → Article in proceedings – Annual report year: 2008 → Research → peer-review

The effect of using low-polluting building materials on perceived air quality and ventilation requirements in real rooms

General information
The effects of electrostatic particle filtration and supply-air filter condition in classrooms on the performance of schoolwork by children (RP-1257)

Two independent field intervention experiments involving a total of about 190 pupils were carried out in winter and early spring of 2005 in five pairs of mechanically ventilated classrooms that received 100% outdoor air. Each pair of classrooms was located in a different static air cleaners were installed in classrooms and either operated or disabled to modify particle concentrations while the performance of schoolwork was measured. In one school, the used supply-air filters in a ventilation system without recirculation were also replaced with new ones to modify classroom air quality, while the filters in use in other schools were not changed. The conditions were established for one week at a time in a blind crossover design with repeated measures on ten-to-twelve-year-old children. Pupils performed six exercises exemplifying different aspects of schoolwork as part of normal lessons and indicated their environmental perceptions and the intensity of any symptoms. A sensory panel of adults judged the air quality in the classrooms soon after the pupils left. Operating the electrostatic air cleaners considerably reduced the concentration of particles in the classrooms. The effect was greater the lower the outdoor air supply rate. There were no consistent effects of this reduction on the performance of schoolwork, on the children's perception of the classroom environment, on symptom intensity, or on air quality as perceived by the sensory panel. This suggests there are no short-term (acute) effects of particle effects were inconsistent, removal outside the pollen season. When new filters were installed, the e although this is believed to be due to sequential and unbalanced presentation of filter conditions and to the fact that the used filters retained very little dust.

The influence of ozone on self-evaluation of symptoms in a simulated aircraft cabin

Simulated 4-h flights were carried out in a realistic model of a three-row, 21-seat section of an aircraft cabin that was reconstructed inside a climate chamber. Twenty-nine female subjects, age 19-27 years, were split into two groups; each group was exposed to four conditions: two levels of ozone
The performance of schoolwork by children is not affected by short-term electrostatic particle filtration outside the pollen season

Window-opening behaviour when classroom temperature and air quality are manipulated experimentally (ASHRAE 1257-RP)

Thermal and Indoor Air Quality Effects on Physiological Responses, Perception and Performance of Tropically Acclimatized People
Effect of using low-polluting building materials and increasing ventilation on perceived indoor air quality

IEQ factors that affect human performance. Status

Improving indoor air quality improves the performance of office work and schoolwork
Improving Indoor Air Quality Improves the Performance of Office Work and Schoolwork and Provides Economic Benefits:
Summary of Research by the International Centre for Indoor Environment and Energy

The effects of moderately raised classroom temperatures and classroom ventilation rate on the performance of schoolwork by children (RP-1257)
Two independent field intervention experiments were carried out in school classrooms in late summer (in 2004 and 2005). The air temperature was manipulated by either operating or idling split cooling units installed for the purpose. In one of these experiments, the outdoor air supply rate was also manipulated. The conditions were established for one week at a time in a blind crossover design with repeated measures on two classes of 10- to 12-year-old children. Six to eight exercises exemplifying different aspects of schoolwork (numerical and language-based) were performed as part of normal lessons. Pupils indicated their environmental perceptions and the intensity of any symptoms on visual analogue scales. Their thermal sensation changed from slightly too warm to neutral, and the performance of two numerical and two language-based tests was significantly improved when the temperature was reduced from 25 degrees C to 20 degrees C (77 degrees F to 68 degrees F). When the outdoor air supply rate was increased from 5.2 to 9.6 L/s (11.0 to 20.3 cfm) per person, their performance of four numerical exercises improved significantly, confirming the results of previously reported experiments in the same series. The above improvements were mainly in terms of the speed at which tasks were performed, with negligible effects on error rate. Most school classrooms worldwide experience raised air temperatures during increased thermal loads, e.g., in warm weather; these results show that providing some means of avoiding elevated temperatures would improve educational attainment.
The effects of outdoor air supply rate and supply air filter condition in classrooms on the performance of schoolwork by children (1257-RP)

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Wargocki, P., Wyon, D. P.
Pages: 165-191
Publication date: 2007
Peer-reviewed: Yes

Publication information
Journal: Hvac&r Research
Volume: 13
Issue number: 2
ISSN (Print): 2374-4731
Ratings:
Scopus rating (2007): SJR 0.677 SNIP 1.639
Web of Science (2007): Indexed yes
Original language: English
Source: orbit
Source-ID: 210602
Research output: Contribution to journal › Journal article – Annual report year: 2007 › Research › peer-review

Two independent field intervention experiments were carried out in mechanically ventilated classrooms receiving 100% outdoor air. Outdoor air supply rate and filter condition were manipulated to modify indoor air quality, and the performance of schoolwork was measured. The conditions were established for one week at a time in a blind crossover design with repeated measures on 10- to 12-year-old children in two classes. Seven exercises exemplifying different aspects of schoolwork (numerical or language-based) were performed as part of normal lessons by pupils who also marked visual analogue scales to indicate their environmental perceptions and the intensity of any symptoms. The children indicated that the air was fresher but otherwise perceived little difference when the outdoor air supply rate increased from 3.0 to 8.5 L/s (6.4-18 cfm) per person, while the speed at which they performed two numerical and two language-based tasks improved significantly. A significant effect of ventilation rate was observed in 70% of all the statistical tests for an effect on work rate, but there were no significant effects on errors. The effects were probably due to improved air quality in the classrooms as judged by a sensory panel of adults blind to conditions, as perceived by children, and as indicated by the reduction in the average CO2 concentration from 1300 to 900 ppm, taking this as a marker of reduced bioeffluent concentration. It was not possible to test the effect of replacing a soiled filter with a new one because very little dust had been retained by the "used" filter and because of an incompletely balanced design. The unbalanced design also made it impossible to test for an interaction between filter condition and ventilation rate. These results indicate the importance of improving indoor air quality and ventilation in classrooms.
Effect of ventilation on perceived quality of air polluted by building materials - a summary of reported data

Effects of HVAC on student performance

Effects of outdoor air supply rates on call handling performance in three call centers in the tropics
Effects of outdoor air supply rates on subjective factors in three call centers in the Tropics (a principal component analysis approach)

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Willem, H. C., Tham, K., Wargocki, P., Wyon, D. P., Fanger, P. O.
Pages: 69-73
Publication date: 2006

Host publication information
Title of host publication: Proceedings of Healthy Buildings 2006 : Lisboa, Portugal
Volume: I
Source: orbit
Source-ID: 189570
Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 2006

Effects of ozone chemistry and outside air supply on passenger self-evaluation of symptoms during 4-hour exposures in a simulated aircraft cabin

Experiments were carried out in a simulated 21-seat section of an aircraft cabin, installed in a climate chamber, to determine the extent to which cabin air quality and passenger symptoms are affected by ozone chemistry. A total of 30 subjects were exposed to four conditions: two rates of outside flow with and without ozone. The subjects completed questionnaires to provide subjective assessments of air quality, cabin environment, intensity of symptoms commonly experienced during flight, and thermal comfort. Physiological tests, specifically Visual Acuity, Nasal Peak Flow and Skin Dryness, were also performed.

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering, Silesian University of Technology
Number of pages: 636
Publication date: 2006

Host publication information
Title of host publication: Proceedings of Healthy Buildings 2006: Lisbon, Portugal
Volume: Abstracts
Place of publication: Portugal
Editors: Fernandes, E. D. O., Silva, M. G. D., Pinto, J. R.
ISBN (Print): 978-989-95067-0-1
Source: orbit
Source-ID: 189866
Research output: Chapter in Book/Report/Conference proceeding – Conference abstract in proceedings – Annual report year: 2006

Indeklima og produktivet

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Indoor air quality effects on office work

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Wyon, D. P., Wargocki, P.
Pages: 193-205
Publication date: 2006

Host publication information
Title of host publication: Creating the Productive Workplace
Volume: 12
Place of publication: London
Publisher: Taylor & Francis
Editor: Clements-Croome, D.
Edition: 2nd
Source: orbit
Source-ID: 189888
Research output: Chapter in Book/Report/Conference proceeding – Book chapter – Annual report year: 2006 – Research

Indoor climate and productivity in offices: How to integrate productivity in life cycle costs analysis of building services

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Publication date: 2006

Publication information
Place of publication: Brussels
Publisher: REHVA
Edition: 1
ISBN (Print): 2-9600468-5-4
Original language: English
Source: orbit
Source-ID: 189568
Research output: Book/Report – Book – Annual report year: 2006 – Education

Is it economically justified to invest in high indoor air quality?

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Wargocki, P.
Pages: 355-360
Publication date: 2006

Host publication information
Title of host publication: Proceeding of the 17th air-conditioning and ventilation conference: Prague, May 17-19, Czech Republic
Perceived Air Quality of an Occupied, Ozone Exposed, Simulated Aircraft Cabin

Perceived air quality was studied in a simulated aircraft cabin. Four different air quality conditions were created at low and high air change rates in the presence and absence of ozone. Two additional assessments of air quality were also performed at high outdoor airflow rates in the absence of people both in the presence and absence of ozone. The results showed significant differences between the conditions with and without ozone. No significant differences were found either between the conditions with high and low air change rates or in the presence or absence of people.

Room temperature effects on office work

The performance of schoolwork by children is affected by classroom air quality and temperature
Cerebral blood flow, fatigue, mental effort and task performance in an office with two different pollution loads

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering, Waseda University
Contributors: Nishihara, N., Wargocki, P., Wyon, D., Fanger, P. O., Tanabe, S.
Pages: 377-382
Publication date: 2005

Host publication information
Title of host publication: Proceedings of Indoor Air 2005, The 10th International Conference on Indoor Air Quality and Climate, Beijing, China
Volume: 1
Source: orbit
Source-ID: 184917
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2005 › Research › peer-review

Comparison of different methods for quantifying indoor air quality based on the study on the influence of the photocatalytic air cleaning on the air quality in the office polluted by typical building materials

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Skorek, A., Wargocki, P., Famula, B.
Publication date: 2005

Host publication information
Title of host publication: Proceeding of International Conference on Energy Efficient Technologies in Indoor Environment
Volume: CD-ROM
Source: orbit
Source-ID: 184927
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2005 › Research

Effect of photocatalytic air purifier on perceived indoor air quality

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Kolarik, J., Wargocki, P.
Pages: 52-57
Publication date: 2005

Host publication information
Title of host publication: Proceedings of Indoor Air 2005, The 10th International Conference on Indoor Air Quality and Climate, Beijing, China
Volume: I/1
Source: orbit
Source-ID: 184916
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2005 › Research › peer-review

Effects of indoor pollution sources and ventilation rate on ozone's surface removal rate and the occurrence of oxygenated VOCs in an office space

General information
Publication status: Published
Effects of indoor pollution sources and ventilation rate on ozone surface removal rate and the occurrence of oxygenated VOCs in an office space

High indoor air quality improves office work and provides economic benefits

Measurements of perceived air quality
Objective methods for measuring effects of low dose exposures on humans indoors

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Barna, E., Wargocki, P., Sundell, J.
Pages: 3787-3791
Publication date: 2005

Host publication information
Title of host publication: Proceedings of Indoor Air 2005, The 10th International Conference on Indoor Air Quality and Climate, Beijing
Volume: V
Source: orbit
Source-ID: 184915

Poor indoor air quality slows down metabolic rate of office workers

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Bako-Biro, Z., Wargocki, P., Wyon, D., Fanger, P. O.
Pages: 76-80
Publication date: 2005

Host publication information
Title of host publication: Proceedings of Indoor Air 2005, The 10th International Conference on Indoor Air Quality and Climate, Beijing, China
Volume: I/1
Source: orbit
Source-ID: 184914

PTR-MS measurements in indoor environments

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Pages: 60-61
Publication date: 2005

Host publication information
Title of host publication: Proceedings of 2nd International Conference on Proton Transfer Reaction Mass Spectrometry and Its Applications, Contributions, Institut für Ionenphysik, Innsbruck, Austria
Source: orbit
Source-ID: 184921

Simulations of the potential revenue from investment in improved indoor air quality in an office building

The annual costs of energy and maintenance in running a heating, ventilation and air-conditioning (HVAC) system and life-cycle costs (LCC) of investments for improving air quality in an office building were compared with the resulting revenues from increased office productivity as a consequence of improved worker performance; benefits from reduced health costs and sickness absence were not included. The building was simulated in a cold, a moderate and a hot climate. It was ventilated by a constant air volume (CAV) system with heat recovery and by a variable air volume (VAV) system with an economizer. The air quality was improved by increasing the outdoor air supply rate and by reducing the pollution loads. These upgrades involved increased energy and HVAC maintenance costs, first costs of a HVAC system and building construction costs. But the additional investments were highly cost-effective. The annual benefit due to improved air quality was up to 115 times higher than the increase in annual energy and maintenance costs. LCC analysis showed that
productivity benefits resulting from a better indoor air quality were up to 60 times higher than the increased costs; the simple and discounted pay-back time were below 2.1 years; and the annual rate of return was 4-7 times higher than the minimum rate set at 3.2%. Present data, although obtained by simulations, constitute a strong incentive for providing indoor air of a quality that is better than the minimum levels required by present standards.

**General information**
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Wargocki, P., Djukanovic, R.
Pages: 699-711
Publication date: 2005
Peer-reviewed: Yes

**Publication information**
Journal: A S H R A E Transactions
Volume: 111
Issue number: 2
ISSN (Print): 0001-2505
Ratings:
Scopus rating (2005): SJR 0.483 SNIP 0.807
Original language: English
Source: orbit
Source-ID: 184910
Research output: Contribution to journal › Journal article – Annual report year: 2005 › Research › peer-review

The effect of reducing pollution sources and photocatalytic air purifier quantified with proton-transfer-reaction mass spectrometry

**General information**
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Skorek, A., Wargocki, P., Wisthaler, A.
Pages: 2945-2949
Publication date: 2005

**Host publication information**
Title of host publication: Proceedings of Indoor Air 2005, The 10th International Conference on Indoor Air Quality and Climate, Beijing, China
Volume: IV
Source: orbit
Source-ID: 184919
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2005 › Research › peer-review

The effects of classroom air temperature and outdoor air supply rate on performance of school work by children

**General information**
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Wargocki, P., Wyon, D., Matysiak, B., Irgens, S.
Pages: 368-372
Publication date: 2005

**Host publication information**
Title of host publication: Proceedings of Indoor Air 2005, The 10th International Conference on Indoor Air Quality and Climate, Beijing, China
Volume: I/1
Source: orbit
Source-ID: 184911
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2005 › Research › peer-review
The effects of outdoor air supply rates in classrooms on the performance of schoolwork by children

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Wargocki, P., Wyon, D., Jark, L., Schaub-Hansen, M.
Publication date: 2005

Effects of air pollutants on the carbon dioxide (CO2) emission rate of human subjects
Several laboratory studies have shown the negative effects of emissions from typical indoor pollution sources on perceived air quality, SBS symptoms and the performance of office work. The subjects performed typical office tasks at their own pace while they were exposed for several hours to different air quality conditions. A re-analysis of the CO2 measurements obtained in two independent studies showed that human CO2 emission rates were affected by air quality (P

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Bako-Biro, Z., Wargocki, P., Wyon, D., Fanger, P. O.
Pages: 111-116
Publication date: 2004

Effects of pollution from personal computers on perceived air quality, SBS symptoms and productivity in offices

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Pages: 178-187
Publication date: 2004
Peer-reviewed: Yes
Potential application of a photocatalytic air purifier for improving indoor air quality in buildings

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Skorek, A., Wargocki, P., Famula, B.
PUBLICATION DATE 2004
Peer-reviewed: No
Source: orbit
Source-ID: 155737
Research output: Contribution to conference › Conference abstract for conference – Annual report year: 2004 › Research

Sensory pollution loads in six office buildings and a department store

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Wargocki, P., Fanger, P. O., Krupicz, P., Szczecinski, A.
Pages: 995-1001
Publication date: 2004
Peer-reviewed: Yes

Publication information
Journal: Energy and Buildings
Volume: 36
Ratings:
Scopus rating (2004): SJR 0.854 SNIP 1.66
Web of Science (2004): Indexed yes
Original language: English
Source: orbit
Source-ID: 155916
Research output: Contribution to journal › Journal article – Annual report year: 2004 › Research › peer-review

Sensory pollution sources in buildings

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Wargocki, P.
Pages: 82-91
Publication date: 2004
Peer-reviewed: Yes

Publication information
Journal: Indoor Air
Volume: 14
Issue number: Suppl. 7
ISSN (Print): 0905-6947
Ratings:
Web of Science (2004): Indexed yes
Original language: English
Source: orbit
Source-ID: 155917
Research output: Contribution to journal › Journal article – Annual report year: 2004 › Research › peer-review

The effect of photocatalytic air cleaning on perceived air quality

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Skorek, A., Famula, B., Wargocki, P.
The performance and subjective responses of call-center operators with new and used supply air filters at two outdoor air supply rates

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Wargocki, P., Wyon, D., Fanger, P. O.
Pages: 7-16
Publication date: 2004
Peer-reviewed: Yes

Publication information
Journal: Indoor Air
Volume: 14
Issue number: Suppl. 8
ISSN (Print): 0905-6947
Ratings:
Web of Science (2004): Indexed yes
Original language: English
Source: orbit
Source-ID: 155937
Research output: Contribution to journal › Journal article – Annual report year: 2004 › Research › peer-review

Call-centre operator performance with new and used filters at two outdoor air supply rates

General information
Publication status: Published
Organisations: Department of Mechanical Engineering
Pages: 213-218
Publication date: 2003

Host publication information
Title of host publication: Proceedings of Healthy Buildings 2003
Volume: 3
Place of publication: Singapore
Publisher: Healthy Buildings
Source: orbit
Source-ID: 25597
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2003 › Research › peer-review

Chemical emission rates from personal computers
Chemical emission measurements from different brands of personal computers (PCs) were conducted in a 1 m3 glass chamber. Eight PCs were tested individually. Each consisted of the same brand of PC tower and one of the 4 different brands of PC monitors. Within each brand both cathode-ray tube (CRT) and thin-film transistor (TFT) flat panel monitors were evaluated. Volatile organic compounds (VOCs) and aldehydes were quantified using GC/MS and HPLC, respectively. Compared with PCs with TFT monitors, PCs with CRT monitors had slightly higher emission rates of formaldehyde and acetaldehyde, emitted greater quantities of C3-C6 aldehydes having low odor thresholds and had higher emissions of aromatic hydrocarbons. Emission rates of aliphatic hydrocarbons were low for both PCs with CRT and TFT monitors. However, estimated concentrations of these chemicals in a normal office space based on the measured emission rates were much lower than the odour thresholds.
Sensory emission rates from personal computers and television sets

Sensory emissions from personal computers (PCs), PC monitors + PC towers, and television sets (TVs) having been in operation for 50, 400 and 600 h were assessed by a panel of 48 subjects. One brand of PC tower and four brands of PC monitors were tested. Within each brand, cathode-ray tube (CRT) and thin-flat-transistor (TFT) monitors were selected. Two brands of TVs were tested. All brands are prevalent on the world market. The assessments were conducted in low-polluting 40 m³ test offices ventilated with a constant outdoor air change rate of 1.3 ± 0.2 h⁻¹ corresponding to 7 L/s per PC or TV with two units placed at a time in the test offices; air temperature was controlled at 22 ± 0.1°C and relative humidity at 41 ± 0.5%. The subjects entered the offices individually and immediately assessed the air quality. They did not see the PCs or TVs that were placed behind a screen and were in operation. The average sensory emission rate for PCs with CRT monitors was 2.7 ± 1.7 olf/PC after 50 h of operation. It decreased to 1.4 ± 1.2 olf/PC when the operation time...
was 600 h, suggesting a half-life equal to 4 months of normal use. The sensory emission rates for PCs with TFT monitors were negligible. The average sensory emission rate for TVs was 1 ± 0.6 olf/TV after 50 h of operation and decreased to a negligible level after 400 h of operation. Present results indicate that air pollution from electronic equipment should be considered when calculating the ventilation requirements for acceptable indoor air quality.

**General information**
- Publication status: Published
- Organisations: Department of Mechanical Engineering, Warsaw University of Technology, Waseda University, Technical University of Denmark
- Pages: 169-175
- Publication date: 2003

**Host publication information**
- Title of host publication: Healthy Buildings 2003 : Proceedings of the 7th International Conference
- Volume: Vol. 3
- Place of publication: Singapore
- Publisher: University of Singapore
- Keywords: Perceived air quality, Sensory, Emissions, Personal computers, Electronic equipment
- Source: orbit
- Source-ID: 25700

**Temperature and ventilation effects on the work performance of office workers: Study of call-centre in the tropics**

**General information**
- Publication status: Published
- Organisations: Indoor Environment, Department of Mechanical Engineering
- Contributors: Wyon, D., Wargocki, P.
- Pages: 280-286
- Publication date: 2003

**Host publication information**
- Title of host publication: Procedings of The Healthy Buildings 2003 Conference
- Place of publication: Singapore
- Editors: Tham, K., Sekhar, C., Cheng, K.
- Source: orbit
- Source-ID: 155823

**The SBS symptoms and environmental perception of office workers in the Tropics at two air temperatures and two ventilation rates**

**General information**
- Publication status: Published
- Organisations: Indoor Environment, Department of Mechanical Engineering
- Contributors: Wyon, D., Wargocki, P.
- Pages: 182-188
- Publication date: 2003

**Host publication information**
- Title of host publication: Procedings of The Healthy Buildings 2003 Conference
- Place of publication: Singapore
- Editors: Tham, K., Sekhar, C., Cheong, K.
- Source: orbit
- Source-ID: 155837

**Air quality in a simulated office environment as a result of reducing pollution sources and increasing ventilation**

Air quality was studied in an office space classified as low-polluting and ventilated with outdoor air at a rate of 1 h-1. The pollution load in the space was changed by introducing or removing common building-related indoor pollution sources
(linoleum, sealant and wooden shelves with books and paper documents) so that the space could no longer be classified as low-polluting. The outdoor air supply rate in the office was altered from 1 to 3 h⁻¹ (0.83 and 2.5 l/s per m² floor, respectively) when sources were present and absent. Air temperature of 23 deg.C, relative humidity of 50% and noise level of 35 dB(A) remained unchanged. Under each of the four conditions of air quality in the office, concentrations of volatile organic compounds (VOCs) were measured and perceived air quality was assessed by a panel of 30 female subjects. Removing the sources reduced the chemical and sensory pollution load in the office, and increasing the outdoor air supply rate decreased concentrations of many VOCs, including those emitted by building materials and furnishing, and human bioeffluents. The perceived air quality in the office was consequently improved. The improvement in air quality obtained by removing the sources was similar to that obtained by increasing the outdoor air supply rate. The study, thus, confirmed that the systematic use of low-polluting building materials will lead to improved air quality.

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Wargocki, P., Bako-Biro, Z., Clausen, G., Fanger, P. O.
Pages: pp. 775-783
Publication date: 2002
Peer-reviewed: Yes

Publication information
Journal: Energy and Buildings
Volume: Vol. 34
Ratings:
Scopus rating (2002): SJR 1.171 SNIP 1.63
Web of Science (2002): Indexed yes
Original language: English
Source: orbit
Source-ID: 62424
Research output: Contribution to journal › Journal article – Annual report year: 2002 › Research › peer-review

Call-centre occupant response to new and used filters at two outdoor air supply rates
A 2x2 replicatetd field intervention experiment was conducted in a call-centre providing a public telephone directory service: outdoor air supply rate was 8% or 80% of the total airflow of 430 L/s providing 3.5 h⁻¹; and the supply air filters were either new or used (i.e. used in place for 6 months). Each of these 4 conditions was maintained for a full working week at a time. Room temperature and humidity averaged 24 deg.C and 27% RH. The 26 operators were blind to conditions and assessed perceived air quality (PAQ), the intensity of Sick Building Syndrome (SBS) symptoms and self-estimated performance. Increasing the outdoor air supply rate with a new filter in place significantly alleviated many symptoms, as did changing from used to new supply air filters at the low outdoor air supply rate, but filter condition made little difference at the high outdoor air supply rate.

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Wargocki, P., Wyon, D., Nielsen, J., Fanger, P. O.
Publication date: 2002

Host publication information
Title of host publication: Proceedings of Indoor Air 2002
Source: orbit
Source-ID: 62501
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2002 › Research › peer-review

Comparison between full- and small-scale sensory assessments of air quality
Thirty-nine untrained subjects made small- and full-scale evaluations of the acceptability of the quality of air at 22 deg.C and 40% RH, polluted by either carpet, felt floor covering, painted gypsum board, linoleum or chipboard. Small-scale evaluations were made on the air extracted from 200-L glass chambers ventilated at an airflow of 0.9 L/s. Full-scale assessments were made immediately upon entering offices ventilated at an outdoor air supply rate of 1.9 h⁻¹. The ratio of ventilation rate to surface area of a building material was identical in the chambers and in the offices. Full-scale sensory ratings of acceptability of air polluted by carpet and by linoleum were systematically better than small-scale assessments, but not for the other three materials. Calculated sensory emission rates from carpet and linoleum were significantly lower in full scale than in small scale. When modelling the perceived air quality in spaces, sensory emission rates estimated in small scale may require a correction, probably depending on the nature of the chemicals emitted by a building material.

General information
Cost-benefit analysis of improved air quality in an office building
A cost-benefit analysis of measures to improve air quality in an existing air-conditioned office building (11581 m², 864 employees) was carried out for hot, temperate and cold climates and for two operating modes: Variable Air Volume (VAV) with economizer; and Constant Air Volume (CAV) with heat recovery. The annual energy cost and first cost of the HVAC system were calculated using DOE 2.1E for different levels of air quality (10-50% dissatisfied). This was achieved by changing the outdoor air supply rate and the pollution loads. Previous studies have documented a 1.1% increase in office productivity for every 10% reduction in the proportion of occupants entering a space who are dissatisfied with the air quality. With this assumption, the annual benefit due to improved air quality was always at least 10 times higher than the increase in annual energy and maintenance costs. The payback time of the HVAC first costs involved in improving the air quality was always less than 4 months.

Making the case for IAQ
Present results clearly justify increased initial and operating costs, and provide a strong economic incentive for designing indoor environments with air of a higher quality than the minimum prescribed by the present ventilation standards. The provision of good air quality indoors need not necessarily cost more or require more energy if the building envelope and the HVAC system are designed intelligently, and building and furnishing materials are carefully selected.

Perceived air quality and sensory pollution loads in six Danish office buildings
Perceived air quality and sensory pollution loads were measured in 6 office buildings with mechanical ventilation without recirculation, in each buildings in 6 representative non-smoking medium-sized and small offices with mixing ventilation. An untrained panel of 43 subjects assessed the air quality on a normal weekday when the building was occupied, and on a weekend without occupants in the building. On both occasions the ventilation system was in operation as on a normal working day. Outdoor air supply rate, air temperature, relative humidity, concentration of carbon dioxide and ultrafine particles were measured. The percentage of persons dissatisfied with air quality ranged from 3 to 30%, decreasing with increasing outdoor air supply rate from 1 to 4 L/(s·m²·floor). Total sensory pollution loads ranged from 0.08 to 0.37 olf/m²·floor in occupied buildings and from 0.04 to 0.27 olf/m²·floor in unoccupied buildings. They are somewhat lower than...
the loads measured in earlier studies.

**General information**
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Wargocki, P., Krupicz, P., Szczecinski, A., Fanger, P. O., Clausen, G.
Publication date: 2002

**Host publication information**
Title of host publication: Proceedings of Indoor Air 2002
Source: orbit
Source-ID: 62558
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2002 › Research › peer-review

**Personal computers pollute indoor air: effects on perceived air quality, SBS symptoms and productivity in offices**
Perceived air quality and Sick Building Syndrome (SBS) symptoms were studied in a low-polluting office space ventilated at an air change rate of 2 h⁻¹ (10 L/s per person with 6 people present) with and without personal computers (PCs). Other environmental parameters were kept constant. Thirty female subjects were exposed for 4.8 h to each of the two conditions in the office and performed simulated office work. They remained thermally neutral by adjusting their clothing and were blind to the interventions. In the absence of PCs in the office the perceived air quality improved, odour intensity was reduced and air freshness increased; all effects were significant. In the presence of PCs the performance of text typing significantly decreased. The sensory pollution load of the PCs was found to be 3 olf per PC, i.e. three times the load of the occupants. Present results indicate negative effects of PCs on human comfort and performance.

**General information**
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Publication date: 2002

**Host publication information**
Title of host publication: Proceedings of Indoor Air 2002
Source: orbit
Source-ID: 62561
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2002 › Research › peer-review

**Subjective perceptions, symptom intensity and performance: a comparison of two independent studies, both changing similarly the pollution load in an office**
The present paper shows that introducing or removing the same pollution source in an office in two independent investigations, one in Denmark and one in Sweden, using similar experimental methodology, resulted in similar and repeatable effects on subjective assessments of perceived air quality, intensity of sick building syndrome symptoms and performance of office work. Removing the pollution source improved the perceived air quality, decreased the perceived dryness of air and the severity of headaches, and increased typing performance. These effects were observed separately in each experiment and were all significant (P less than/equal to 0.05) after combining the data from both studies, indicating the advantages of pollution source strength control for health, comfort, and productivity.

**General information**
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Pages: pp. 74-80
Publication date: 2002
Peer-reviewed: Yes

**Publication information**
Journal: Indoor Air
Volume: Vol. 12
ISSN (Print): 0905-6947
Ratings:
Web of Science (2002): Indexed yes
Original language: English
Source: orbit
Source-ID: 62472
The role of ventilation and HVAC systems for human health in nonindustrial indoor environments. A supplementary review by EUROVEN group

A continuation of the earlier work of the multidisciplinary group of European scientists, EUROVEN, is presented. The group has previously concluded that increased ventilation rates in indoor nonindustrial environments are strongly associated with improved comfort and health and may be associated with increased productivity, and that air-conditioning systems may increase the risk of sick building syndrome (SBS) symptoms. Taking these findings into account, the group has elaborated 35 hypotheses on the role of ventilation and HVAC systems in nonindustrial indoor environments with regard to human health; 108 peer-reviewed papers have been reviewed among which 74 supported or refuted the hypotheses. The group concluded that increasing outdoor air supply rates is necessary for dilution/removal of pollutants generated indoors (including allergens), and that improper design, functioning and maintenance of ventilation and air-conditioning systems, as well as their intermittent operation, may be potential reasons for health problems of people staying indoors.

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Publication date: 2002

Ventilation and health in non-industrial indoor environments: report from a European Multidisciplinary Scientific Consensus Meeting (EUROVEN)

Scientific literature on the effects of ventilation on health, comfort, and productivity in non-industrial indoor environments (offices, schools, homes, etc.) has been reviewed by a multidisciplinary group of European scientists, called EUROVEN, with expertise in medicine, epidemiology, toxicology, and engineering. The group reviewed 105 papers published in peer-reviewed scientific journals and judged 30 as conclusive, providing sufficient information on ventilation, health effects, data processing, and reporting, 14 as providing relevant background information on the issue, 43 as relevant but non-informative or inconclusive, and 18 as irrelevant for the issue discussed. Based on the data in papers judged conclusive, the group agreed that ventilation is strongly associated with comfort (perceived air quality) and health (Sick Building Syndrome (SBS) symptoms, inflammation, infections, asthma, allergy, short-term sick leave), and that an association between ventilation and productivity (performance of office work) is indicated. The group also concluded that increasing outdoor air supply rates in non-industrial environments improves perceived air quality; that outdoor air supply rates below 25 l/s per person increase the risk of SBS symptoms, increase short-term sick leave, and decrease productivity among occupants of office buildings; and that ventilation rates above 0.5 air changes per hour (h−1) in homes reduce infestation of house dust mites in Nordic countries. The group concluded additionally that the literature indicates that in buildings with air-conditioning systems there may be an increased risk of SBS symptoms compared with naturally or mechanically ventilated buildings, and that improper maintenance, design, and functioning of air-conditioning systems contributes to increased prevalence of SBS symptoms.

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Pages: pp. 113-128
Publication date: 2002
Peer-reviewed: Yes

Publication information
Journal: Indoor Air
Volume: Vol. 12
ISSN (Print): 0905-6947
Ratings:
Web of Science (2002): Indexed yes
Original language: English
Source: orbit
Increased office productivity by improving indoor air quality

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Fanger, P. O., Wargocki, P.
Publication date: 2001

Host publication information
Title of host publication: Proceedings of CIAR 2001
Publisher: Asociación Argentina del Frio
Source: orbit
Source-ID: 64202
Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 2001
Research: peer-review

Increased office productivity through improved indoor air quality

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Fanger, P. O., Wargocki, P.
Publication date: 2001

Host publication information
Title of host publication: Proceedings of IAQ Symposium
Place of publication: Hong Kong
Publisher: Department of Mechanical Engineering, Hong Kong Polytechnic University
Source: orbit
Source-ID: 64203
Research output: Chapter in Book/Report/Conference proceeding – Annual report year: 2001
Research: peer-review

Measurements of the effects of air quality on sensory perception

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Contributors: Wargocki, P.
Pages: pp. 345-348
Publication date: 2001
Peer-reviewed: Yes

Publication information
Journal: Chemical Senses
Volume: Vol. 26
ISSN (Print): 0379-864X
Ratings:
Scopus rating (2001): SJR 0.893 SNIP 1.103
Web of Science (2001): Indexed yes
Original language: English
Source: orbit
Source-ID: 64108
Research output: Contribution to journal – Journal article – Annual report year: 2001
Research: peer-review

Ventilation and health in nonindustrial indoor environments

General information
Publication status: Published
Organisations: Indoor Environment, Department of Mechanical Engineering
Negative impact of air pollution on productivity: previous Danish findings repeated in new Swedish test room

Pollution source control and ventilation improve health, comfort and productivity

Pollution source control and ventilation improve health, comfort and productivity
Pollution source control and ventilation improve health, comfort and productivity

General information
Publication status: Published
Organisations: Department of Energy Engineering
Contributors: Wargocki, P., Wyon, D., Fanger, P. O.
Pages: 224-230
Publication date: 2000

Host publication information
Title of host publication: Proceedings of Vnútomá Klima Budov '2000
Place of publication: Tatranská Lomnica, Slovakia
Source: orbit
Source-ID: 177337
Research output: Chapter in Book/Report/Conference proceeding → Article in proceedings – Annual report year: 2000 → Research → peer-review

Productivity is affected by the air quality in offices

General information
Publication status: Published
Organisations: Department of Energy Engineering
Contributors: Wargocki, P., Wyon, D., Fanger, P. O.
Pages: 635-640
Publication date: 2000

Host publication information
Title of host publication: Proceedings of Healthy Buildings 2000
Volume: 1
Place of publication: Helsinki, Finland
Source: orbit
Source-ID: 177334
Research output: Chapter in Book/Report/Conference proceeding → Article in proceedings – Annual report year: 2000 → Research → peer-review

The Effects of Outdoor Air Supply Rate in an Office on Perceived Air Quality, Sick Building Syndrome (SBS) Symptoms and Productivity

General information
Publication status: Published
Organisations: Department of Energy Engineering
Contributors: Wargocki, P., Wyon, D., Sundell, J., Clausen, G., Fanger, P. O.
Pages: 222-236
Publication date: 2000
Peer-reviewed: Yes

Publication information
Journal: Indoor Air
Volume: 10
Issue number: 4
ISSN (Print): 0905-6947
Ratings:
Web of Science (2000): Indexed yes
Original language: English
Source: orbit
Source-ID: 177280
Research output: Contribution to journal → Journal article – Annual report year: 2000 → Research → peer-review

A transfer model between perceived air quality judged by a trained panel and by an untrained panel

General information
Publication status: Published
Effects of exposure to noise and indoor air pollution on human perception and symptoms

Field study on the impact of temperature, humidity and ventilation on perceived air quality

Impact of building pollution on productivity and SBS-symptoms of office workers
Impact of ventilation rates on SBS symptoms and productivity in offices

General information
Publication status: Published
Organisations: Department of Energy Engineering
Contributors: Wargocki, P., Fanger, P. O.
Publication date: 1999

Host publication information
Title of host publication: Proceedings of DKV-Jahrestagung
Place of publication: Berlin
Publisher: DKV
Source: orbit
Source-ID: 172567
Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 1999 – Research

Människors komfort och produktivitet

General information
Publication status: Published
Organisations: Department of Energy Engineering
Contributors: Wargocki, P.
Pages: 71-72
Publication date: 1999
Peer-reviewed: No

Publication information
Journal: Energi & Miljö
Issue number: 11
Original language: Swedish
Source: orbit
Source-ID: 172581
Research output: Contribution to journal – Journal article – Annual report year: 1999 – Research

Menneskers komfort og produktivitet

General information
Publication status: Published
Organisations: Department of Energy Engineering
Contributors: Wargocki, P.
Pages: 10-13
Publication date: 1999
Peer-reviewed: No

Publication information
Journal: VVS Bladet1999
Volume: No. 10
Original language: Danish
Source: orbit
Source-ID: 172791
Research output: Contribution to journal – Journal article – Annual report year: 1999 – Research

Perceived air quality, SBS-symptoms and productivity in an office at two pollution loads

General information
Publication status: Published
Organisations: Department of Energy Engineering, Technical University of Denmark
Perceived air quality, Sick Building Syndrome (SBS) symptoms and productivity in an office with two different pollution loads

Human perception, productivity and symptoms related to indoor air quality

Impact of pollution emitted from a carpet on SBS-symptoms and productivity in offices
The "maximum source principle" as a basis for ventilation standards?

General information
Publication status: Published
Organisations: Department of Energy Engineering
Contributors: Fanger, P. O., Wargocki, P.
Pages: 85-86
Publication date: 1998
Peer-reviewed: Yes

Publication information
Journal: Heating/Piping/Air Conditioning
Volume: May
Original language: English
Source: orbit
Source-ID: 169823
Research output: Contribution to journal › Journal article – Annual report year: 1998 › Research › peer-review

Impact of changing the floor material on air quality in an office building

General information
Publication status: Published
Organisations: Department of Energy Engineering
Contributors: Wargocki, P., Fanger, P. O.
Pages: 243-248
Publication date: 1997

Host publication information
Title of host publication: Proc. of Healthy Buildings/IAQ '97
Publisher: Hlthy Bdgs
Source: orbit
Source-ID: 168666
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 1997 › Research › peer-review

Field study on addition of indoor air sensory pollution sources

General information
Publication status: Published
Organisations: Department of Energy Engineering
Contributors: Wargocki, P., Clausen, G., Fanger, P. O.
Publication date: 1996

Host publication information
Title of host publication: Proceedings
Place of publication: Nagoya, Japan
Publisher: 7th International Conference on Indoor Air Quality and Climate
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VOC generation system for indoor air quality studies

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