Energiforbrug og bygningsautomatik

Ville kontorbygninger blive projekteret anderledes, hvis automatikkens elforbrug indgik i energirammen? Et casestudie undersøger, hvor stor en andel af det reelle energiforbrug i en ny kontorbygning, der anvendes til bygningsautomatik.

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International undersøgelse af krav og praksis for boligventilation

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Publication information
Potential of mechanical ventilation for reducing overheating risks in retrofitted Danish apartment buildings from the period 1850-1890 – A simulation-based study

Advancing energy efficient renovation solutions in buildings necessitate adopting high-insulation and airtightness to avoid heat loss through transmission and infiltration, which can result in overheating. Elevated indoor temperatures have a highly negative effect on building occupants’ health, wellbeing and productivity. With the possibility of remote working, people spend more time at home, and therefore addressing the elevated indoor temperatures and the overheating risks in residential buildings proves to be essential. Even more so, as these high temperatures during daytime are followed by consequent high temperatures during night-time, which distorts sleep quality. The current Danish building regulations suggest that the operative temperature in dwellings should not exceed 27 °C for more than 100 hours per year and 28 °C for more than 25 hours per year. However, in many new and renovated dwellings in Denmark the temperature during spring and summer exceeds these measures. The paper presents the first results from a larger study focused on typical Danish apartment buildings from the period 1850-1950 many of which currently undergo extensive renovation. The main objective of the project is to study facade solutions that eliminate overheating. The present paper reports an effect of different ventilation strategies on overheating in renovated apartment buildings from the period 1850-1890. The investigation showed that energy renovation in this type of buildings, including adding insulation and exchanging windows, yielded energy saving of approx. 60%, but resulted in an increase of overheating hours when no mechanical ventilation system was added. All studied mechanical ventilation systems with heat recovery were able to decrease the overheating hours below limit specified by the Danish building code in the case of the building situated in the narrow street canyon. In the absence of shading from surrounding buildings, the CAV ventilation operating with minimum airflow required by the Danish building code reduced overheating hours insufficiently.

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.
Using the PASSYS cell for model-to-model comparison of hygrothermal building envelope simulation tools

IEA-EBC Annex 68 “Indoor Air Quality Design and Control in Low Energy Residential Buildings” is an international collaborative project to provide new insight into methods and strategies for ensuring high indoor air quality in dwellings during both design and operation phase of their life cycle. Within the Annex 68 work, we defined a common exercise, which focusses on model-to-model comparison of different simulation tools to assess their modelling abilities with respect to combined heat, moisture and pollution transfer.

As basis of the common exercise, we selected a model of the PASSYS cell (originally used as a common European outdoor test facility for thermal and solar building research). The PASSYS cell is modelled by using several simulation tools with different modelling capabilities (e.g. 2D hygrothermal building envelope models vs. 3D building energy models). Model comparisons are done at stepwise increased level of complexity starting at simple thermal analysis (heat transfer through walls, internal heat sources, internal long wave radiation, etc.) and ending at pollution emission analysis under operation of HVAC systems (demand controlled ventilation, heating and cooling).

This paper introduces results from the first part of the exercise covering simulations carried out by using following 2D tools CHAMPS-BES, DELPHIN5 and DELPHIN6.


Maintaining daylight quality while ensuring thermal comfort during periods of high solar gain proves to be a challenge in renovated multi-story housing. The objective of this study was to develop guidelines for façade renovation, where overheating problems can only be avoided through façade solutions. As a first step, different shading systems have been investigated and compared in terms of their daylight performance, visual comfort and gaze responsive characteristics. This trio evaluation method is going to be further developed and used for a larger set of selected shading devices.
Design and operation of ventilation in low energy residences – A survey on code requirements and building reality from six European countries and China

One of the key objectives of the IEA Annex 68 research programme entitled “Indoor Air Quality Design and Control in Low Energy Residential Buildings” is to provide a generic guideline for the design and operation of ventilation in residential buildings. Modern and refurnished domestic buildings need to have minimal energy consumption, and at the same time maintain a high level of Indoor Air Quality. The paper reports on preliminary results of an interview survey conducted among different stakeholders involved in design, installation and operation of residential ventilation in countries involved in the Annex. There were two main objectives, firstly, to describe and analyse a transition between actual requirements (national building codes and standards) and current practice. Secondly, to investigate current barriers and challenges regarding installation of mechanical ventilation in residences. In total, 35 interviews from six European countries and China have been analysed, certainly not enough for a representative sample. However, the results provide a valuable snapshot of current practices and insights into potential barriers. The results show that mechanical ventilation with heat recovery is becoming the dominating ventilation system installed in new residences in Europe. However, there are countries, where, due to tradition, national legislation and/or cost reasons, other types of ventilation like mechanical exhaust or manual window ventilation are applied. Demand Controlled Ventilation is often allowed or even recommended in standards, but rarely implemented in practice, except for humidity controlled trickle vents in France. The main barriers against mechanical ventilation with heat recovery seem to be high capital cost, space requirements and duct routing as well as problems resulting from poor construction, lack of commissioning and/or maintenance.

Indoor air quality in mechanically ventilated residential dwellings/low-rise buildings: A review of existing information

Mechanical ventilation has become a mandatory requirement in multiple European standards addressing indoor air quality (IAQ) and ventilation in residential dwellings (single family houses and low-rise apartment buildings). This article presents the state of the art study through a review of the existing literature, to establish a link between ventilation rate and key indoor air pollutants. Design characteristics of a mechanical ventilation system such as supply/exhaust airflow, system and design of supply and exhaust outlets were considered. The performance of various ventilation solutions was assessed by comparing reported ventilation rates, concentrations of CO₂ and total volatile organic compounds (TVOC) to minimum requirements defined by the latest version of the European Standard EN 15251:2007. Based on the literature review of these parameters, the authors noted that whenever the whole-house ventilation rate was reported below 0.5 h⁻¹ or 14 l/s-person in bedrooms, the concentrations of the pollutants elevated above minimum threshold limits (CO₂ >1350 ppm; TVOC >3000 μg/m³) defined by the standard. Insufficient or non-existent supply of air was related to significantly higher pollutant concentrations. The authors additionally noted that the literature frequently reported the role of improper maintenance and use on deterioration of IAQ in residential dwellings. The summarized data and comments may provide useful information for future guidelines related to ventilation strategies designed for high IAQ in residential dwellings.
**Numerical analysis of the potential of using light radiant ceilings in combination with diffuse ventilation to achieve thermal comfort in NZEB buildings**

Renewable energy resources for heating and cooling of buildings have temperatures close to room temperature and therefore a limited convertibility potential, i.e. they are of low value. To exploit low-valued energy sources Low Temperature Heating and High Temperature Cooling (LTH-HTC) systems must be developed. Hydronic radiant ceiling systems with large surfaces for heat transfer are well suited for the usage of LTH-HTC. In this paper, the aim is to create a system that can be flexible and include ventilation. The system analysed are a suspended capillary tube ceiling placed on top of perforated gypsum ceiling panels. These panels make it possible to combine the heating/cooling ceiling with the diffuse ventilation method. The diffuse ventilation method or leak ventilation use larger surfaces to provide air into the room instead of diffusers.

An office building is investigated an analysed on an annual basis in the dynamic building simulation tool IDA Indoor Climate and Energy (IDA ICE). The office building contains both offices and meeting rooms. Worst-case scenarios are investigated in the office building considering heat gains, solar gains and the temperature offset between supply water temperature and room air temperature. The studies a carried out to identify the potential of reducing the temperature offset in near-zero energy buildings (NZEB) to the level where temperatures between ±2-4 °C becomes possible. The reduction should not compromise on the thermal comfort of the building occupants and comprise energy savings. The investigations showed that with a NZEB building it was possible to create an adequate thermal comfort with a minimum use of energy. The studies showed that an energy saving of 36-41 % from a fan coil system running with the same temperatures was possible.

**Visual Comfort Evaluation in Residential Buildings: a Simulation-Based Study**

Despite desirability of direct sunlight access in residential buildings, visual discomfort risks for these building types are less known. A simulation-based study was performed on a typical residential building with heritage value in central Copenhagen in order to evaluate its visual comfort characteristics using existing methods. Our results show that, although high relative contrast exist for view-directions not only towards window, these situations are not captured by the existing methods. A new method for quantification of a relative contrast over the 360° span of the space was thus introduced.
An International Project on Indoor Air Quality Design and Control in Low Energy Residential Buildings

In order to achieve nearly net zero energy use, both new and energy refurbished existing buildings will in the future need to be still more efficient and optimized. Since such buildings can be expected to be already well insulated, airtight, and have heat recovery systems installed, one of the next focal points to limiting energy consumption for thermally conditioning the indoor environment will be to possibly reducing the ventilation rate, or making it in a new way demand controlled. However, this must be done such that it does not have adverse effects on indoor air quality (IAQ).

Annex 68, Indoor Air Quality Design and Control in Low Energy Residential Buildings, is a project under IEA's Energy Conservation in Buildings and Communities Program (EBC), which will endeavor to investigate how future residential buildings are able to have very high energy performance whilst providing comfortable and healthy indoor environments. New paradigms for demand control of ventilation will be investigated, which consider the pollution loads and occupancy in buildings. As well, the thermal and moisture conditions of such advanced building shall be considered because of interactions between the hygrothermal parameters, the chemical conditions, ventilation and the wellbeing of occupants.

The project is divided into the five subtasks: 1. Defining the metrics. 2. Pollutant loads in residential buildings. 3. Modeling. 4. Strategies for design and control of buildings. 5. Field measurements and case studies. A flagship outcome of the project will be a guidebook on design and operation of ventilation in residential buildings to achieve high IAQ with least possible energy consumption. The paper illustrates the working program of each of these activities.

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Challenging the assumptions for thermal sensation scales

Scales are widely used to assess the personal experience of thermal conditions in built environments. Most commonly, thermal sensation is assessed, mainly to determine whether a particular thermal condition is comfortable for individuals. A seven-point thermal sensation scale has been used extensively, which is suitable for describing a one-dimensional relationship between physical parameters of indoor environments and subjective thermal sensation. However, human thermal comfort is not merely a physiological but also a psychological phenomenon. Thus, it should be investigated how scales for its assessment could benefit from a multidimensional conceptualization. The common assumptions related to the usage of thermal sensation scales are challenged, empirically supported by two analyses. These analyses show that the relationship between temperature and subjective thermal sensation is non-linear and depends on the type of scale used. Moreover, the results signify that most people do not perceive the categories of the thermal sensation scale as equidistant and that the range of sensations regarded as ‘comfortable’ varies largely. Therefore, challenges known from experimental psychology (describing the complex relationships between physical parameters, subjective perceptions and measurement-related issues) need to be addressed by the field of thermal comfort and new approaches developed.

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Effect of building renovation on energy use and indoor environment: Comparison of simulations and measurements in six apartment buildings

Energy performance and the indoor environmental quality (IEQ) in three naturally ventilated original and three identical but renovated residential buildings were compared using actual measurements. Although the implemented energy saving measures had the potential to improve energy performance of the dwellings, they led to poorer indoor air quality (IAQ). Additional simulations revealed that a simple intervention, such as using exhaust systems in kitchens and bathrooms and at the same time keeping doors of rooms open, may improve the IAQ in retrofitted multifamily buildings.

IEA Project on Indoor Air Quality Design and Control in Low Energy Residential Buildings

Both new and renovated existing buildings will in the future need to be optimized in such a way that can achieve to have nearly no energy use while still providing impeccable indoor climates. Since such buildings can already be assumed to be very well insulated, airtight, and to be equipped with heat recovery systems, one of the next focal points to limiting energy consumption for thermally conditioning the indoor environment will be to possibly reducing the ventilation rate, or to make it in a new way demand controlled. However, this must be done such that it has no have adverse effects on Indoor Air Quality (IAQ).

Annex 68, Indoor Air Quality Design and Control in Low Energy Residential Buildings, is a project under IEA’s Energy Conservation in Buildings and Communities Program (EBC), which will endeavor to investigate how future residential buildings are able to have very high energy performance whilst providing comfortable and healthy indoor environments. New paradigms for demand control of ventilation will be investigated, which consider the pollution loads and occupancy in buildings. The thermal and moisture conditions of such will be considered because of interactions between the hygrothermal parameters, the chemical conditions, ventilation and the wellbeing of occupants. A flagship outcome of the project is anticipated to be a guidebook on design and operation of ventilation in residential buildings to achieve high IAQ with smallest possible energy consumption.
**Key figures for joint assessment of indoor environmental quality (IEQ) and energy consumption in modern buildings – a literature review**

Energy efficiency in buildings should not be reached on the expense of indoor environmental quality (IEQ). This statement is often used in connection to design and certification of sustainable buildings. The fact that it is also valid during the actual operation seems to be often forgotten. Nodaway's energy management and operational diagnostics focus mostly on energy consumption. Consequently also present key figures comprise performance indicators related to energy use. The fact that modern buildings are not spared from IEQ related problems indicates that there is a need for joint assessment of energy and IEQ performance. The aim of this paper was to review relevant literature to form a scientific background for development of key figures enabling the joint assessment of energy and IEQ. The review resulted in forty cited publications. Majority of them focused explicitly on energy performance and indoor environment was mentioned only marginally or was not mentioned at all. We can also conclude that energy related key figures are well established and used for standard energy management as well as in different optimization algorithms involving analysis of measurements and calibrated simulations. One publication was identified that integrates thermal comfort into broader matrix of key figures. Methods for long-term evaluation of IEQ indicators suggested by standard EN 15251 seems to be usable for determination of key figures for joint assessment. Further research is needed to determine and test key figures that would directly combine performance indicators related to both energy use and IEQ.

**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.
Thermo Active Building Systems (TABS) - Performance in practice and possibilities for optimization

The project “Thermo Active Building Systems (TABS) – Performance in practice and possibilities for optimization” was carried out at DTU Byg in the period form 1.9.2012 until 31.12.2014. The aim of the project was to conduct field measurements in modern office buildings equipped with TABS systems to fill the gap in missing data on the practical performance of such buildings. The project comprised both field data collection regarding indoor environmental quality and occupant satisfaction and analyses of data from Building Management Systems (BMS) accompanied by building energy simulations.

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Unsteady-state human-body exergy consumption rate and its relation to subjective assessment of dynamic thermal environments

Few examples studied applicability of exergy analysis on human thermal comfort. These examples relate the human-body exergy consumption rate with subjectively obtained thermal sensation votes and had been based on steady-state calculation methods. However, humans are rarely exposed to steady-state thermal environments. Therefore, the first objective of the current paper was to compare a recently introduced unsteady-state model with previously used steady-state model using data obtained under both constant and transient temperature conditions. The second objective was to explore a relationship between the human-body exergy consumption rate and subjective assessment of thermal environment represented by thermal sensation as well as to extend the investigation towards thermal acceptability votes.

Comparison of steady-state and unsteady-state model showed that results from both models were comparable when applied to data from environments with constant operative temperature. In contrast, when applied to data with temperature transients the prediction of particular models differed significantly and the unsteady-state model resulted in better prediction of mean skin temperature. The results of the present study confirmed previously indicated trends that lowest human body exergy consumption rate is associated with thermal sensation close to neutrality. Moreover, higher acceptability was in general associated with lower human body exergy consumption rate. (C) 2016 Elsevier B.V. All rights reserved.

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Agent-Based Decision Control—How to Appreciate Multivariate Optimisation in Architecture

Early stage building performance optimisation as a viable approach is yet to be applied efficiently in building design processes, especially in the early design stages where the design space is open and changes are inexpensive. This article proposes a method of entire building energy optimisation in the early design stage. The main focus is to demonstrate the optimisation method, which is done in two ways. Firstly, the newly developed agent-based optimisation algorithm named Moth is tested on three different single objective search spaces. Here Moth is compared to two evolutionary algorithms. Secondly, the method is applied to a multivariate optimisation problem. The aim is specifically to demonstrate optimisation for entire building energy consumption, daylight distribution and capital cost. Based on the demonstrations Moth's ability to find local minima is discussed. It is concluded that agent-based optimisation algorithms like Moth open up for new uses of optimisation in the early design stage. With Moth the final outcome is less dependent on pre- and post-processing, and Moth allows user intervention during optimisation. Therefore, agent-based models for optimisation such as Moth can be a powerful substitute for traditional stochastic optimisation.

Field measurements of perceived air quality and concentration of volatile organic compounds in four offices of the university building

Field measurements of perceived air quality were conducted in four refurbished offices at the Czech Technical University in Prague. The offices were refurbished as part of the research project Clear-up to serve as a field test facility. The present paper describes measurements conducted to investigate the perceived air quality, sensory pollution load and concentration of Volatile Organic Compounds (VOCs) in the offices. As the refurbishment comprised also installation of demand controlled ventilation (DCV), its influence on the perceived air quality was also tested. Measurements comprised the assessments of perceived air quality and objective measurements of operative temperature, relative humidity, CO₂ and VOCs concentrations. Results showed that the mean sensory pollution load in unoccupied offices was 0.09±0.01 olf/m² (mean±SEM). This falls into the category of a low-polluting building according to CEN Report CR 1752. The acceptability of the air quality was worst in unoccupied offices ventilated with minimum air change rate (0.4 h⁻¹). Application of DCV decreased the CO₂ concentration, but did not result in statistically significant improvement of perceived air quality.
Modern buildings are usually equipped with advanced climate conditioning systems to ensure comfort of their occupants. However, analysis of their actual operation usually identifies large potential for improvements with respect to their efficiency. Present study investigated potential for improvements in an existing office building – a Town Hall of Viborg, Denmark. Thorough field measurements of indoor environment and occupant satisfaction survey were conducted to identify and describe indoor environmental quality problems. Collected data were also used to calibrate computer simulation model, which was used for optimization of building’s performance. Proposed optimization scenarios bring 21-37% reduction on heating consumption and thermal comfort improvement by 7-12%. The approach (procedure) can help to optimize building operation and shorten the adjustment period.

Influence of measurement uncertainty on classification of thermal environment in buildings according to European Standard EN 15251

European Standard EN 15 251 in its current version does not provide any guidance on how to handle uncertainty of long term measurements of indoor environmental parameters used for classification of buildings. The objective of the study was to analyze the uncertainty for field measurements of operative temperature and evaluate its effect on categorization of thermal environment according to EN 15251. A data-set of field measurements of operative temperature four office buildings situated in Denmark, Italy and Spain was used. Data for each building included approx. one year of continuous measurements of operative temperature at two measuring points (south/south-west and north/northeast orientation). Results of the present study suggest that measurement uncertainty needs to be considered during assessment of thermal
environment in existing buildings. When expanded standard uncertainty was taken into account in categorization of thermal environment according to EN 15251, the difference in prevalence of exceeded category limits were up to 17.3%, 8.3% and 2% of occupied hours for category I, II and III respectively.

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Operative temperature drifts and occupant satisfaction with thermal environment in three office buildings using radiant heating/cooling system
The objective of this study was to analyse operative temperature drifts and occupant satisfaction with thermal environment in office buildings utilizing embedded radiant heating/cooling systems. Three office buildings were investigated: Town Hall in Viborg, Denmark (floor area 19400 m²), IDOM, Madrid, Spain (16000 m²), TiFS, Padua, Italy (2200 m²). Continuous measurements of operative temperature were conducted at four workplaces in each building for one year. Occupants’ satisfaction was assessed by internet based questionnaire. Results showed that mostly exceeded limits were those for 4-hour drift (0.8 K/h), which were exceeded at least in 2% and up to 52% of occupied time in investigated buildings. Limits for hourly and 2-hour drifts were exceeded in max. 2% of occupied time. Median values were in ranges of 0.12-0.29 K/h, 0.18-0.52 K/h and 0.27-0.84 K/h for 1, 2 and 4-hour drifts respectively. Occupants’ in all buildings were rather satisfied with temperature conditions. Median temperature satisfaction (0="Clearly satisfied" - 5="Clearly dissatisfied") was 2, 1 and 1 for Viborg, Madrid and Padua respectively. Temperature satisfaction slightly decreased when rate of temperature change increased, thus higher temperature drifts seemed to lead to higher dissatisfaction, however the collected data did not allow for robust statistical analysis.

Using measured indoor environment parameters for calibration of building simulation model—A passive house case study

Using measured indoor environment parameters for calibration of building simulation model—A passive house case study

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The study investigated performance of two commercially available non-selective metal oxide semiconductor VOC sensors and two commercially available non-dispersive infrared CO2 sensors installed in one person office. The office was equipped with demand controlled ventilation. The signals from VOC and CO2 sensors, presence detection sensor and supply/return air flow were logged. VOC and CO2 signals were in agreement with respect to indicated need for mechanical ventilation for 49 % of occupied time (81 % of whole measuring period). VOC measurement would clearly trigger the mechanical ventilation in contradiction with CO2 measurement in 11 % of occupied time. Opposite situation was observed in 6 % of occupied time. In approx. 22 % of occupied time CO2 signal has just reached the set-point while the VOC signal was significantly below. In that case the ventilation start up would be dependent on settings of a particular controller.

Investigating peoples’ preferences of automated indoor climate control facilities

The study investigated the performance of two commercially available non-selective metal oxide semiconductor VOC sensors and two commercially available non-dispersive infrared CO2 sensors installed in one person office. The office was equipped with demand controlled ventilation. The signals from VOC and CO2 sensors, presence detection sensor and supply/return air flow were logged. VOC and CO2 signals were in agreement with respect to indicated need for mechanical ventilation for 49 % of occupied time (81 % of whole measuring period). VOC measurement would clearly trigger the mechanical ventilation in contradiction with CO2 measurement in 11 % of occupied time. Opposite situation was observed in 6 % of occupied time. In approx. 22 % of occupied time CO2 signal has just reached the set-point while the VOC signal was significantly below. In that case the ventilation start up would be dependent on settings of a particular controller.
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.

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

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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 phosphorus 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.

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Field Measurements of Perceived Air Quality in the Test-Bed for Innovative Climate Conditioning Technologies
Field measurements of perceived air quality were conducted in an experimental test bed for innovative building technologies situated at the Czech Technical University in Prague. The technologies included photocatalytically active paint, vacuum porous insulation and wall plaster containing phase change material. Technologies were installed in eight offices as part of the research project Clear-up. The offices were primarily used to carry out comparative tests for individual technologies. The present paper describes measurements done in parallel to the comparative tests to investigate the potential influence of aforementioned technologies on the perceived air quality. Additionally, the effect of Demand Controlled Ventilation (DCV) on the perceived air quality was tested. Measurements comprised of the assessments of perceived air quality and objective measurements of operative temperature, relative humidity and CO₂ concentration. Results showed that the mean sensory pollution load in the tested offices was 0.09±0.02 olf/m².
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.

**The impact of a photocatalytic paint on indoor air pollutants: Sensory assessments**

The ability of a commercial photocatalytically active cement-based paint to improve the perceived air quality was evaluated. The paint was applied to pieces of gypsum board with a total surface area of 13 m² (23% of the total wall surface). To initiate the photocatalytic activity, the paint was illuminated by bulbs emitting visible/UV light. A mixture of common indoor pollutants, including emissions from chipboard, linoleum and carpet, as well as human bioeffluents and isopropanol, were used to test the efficacy of the paint. A sensory panel of 35 subjects assessed the air quality in the test-room once before and twice after a step-change in the room condition (i.e., either a change in the sensory pollution load or the illumination of the paint). Illumination of the paint in the room polluted with building materials significantly decreased the acceptability of the air quality at both 40% (p < 0.01) and 95% (p < 0.05) of the final steady-state condition. Introduction of bioeffluents significantly affected the perceived air quality only shortly after the step-change (40% steady-state); with non-illuminated paint the acceptability decreased; with illuminated paint the acceptability increased. Emission of isopropanol at 1 cm³/h had no effect on the perceived air quality (both with and without illumination).

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A relation between calculated human body exergy consumption rate and subjectively assessed thermal sensation

Application of the exergy concept to research on the built environment is a relatively new approach. It helps to optimize climate conditioning systems so that they meet the requirements of sustainable building design. As the building should provide a healthy and comfortable environment for its occupants, it is reasonable to consider both the exergy flows in building and those within the human body. Until now, no data have been available on the relation between human-body exergy consumption rates and subjectively assessed thermal sensation. The objective of the present work was to relate thermal sensation data, from earlier thermal comfort studies, to calculated human-body exergy consumption rates. The results show that the minimum human body exergy consumption rate is associated with thermal sensation votes close to thermal neutrality, tending to the slightly cool side of thermal sensation. Generally, the relationship between air temperature and the exergy consumption rate, as a first approximation, shows an increasing trend. Taking account of both convective and radiative heat exchange between the human body and the surrounding environment by using the calculated operative temperature, exergy consumption rates increase as the operative temperature increases above 24 °C or decreases below 22 °C. With the data available so far, a second-order polynomial relationship between thermal sensation and the exergy consumption rate was established.

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Effects on perceived air quality of a photocatalytic cement-based paint tested under steady-state and transient conditions

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Exergy analysis: The effect of relative humidity, air temperature and effective clothing insulation on thermal comfort

Exergy analysis enables us to make connections among processes inside the human body and processes in a building. So far, only the effect of different combinations of air temperatures and mean radiant temperatures have been studied, with constant relative humidity in experimental conditions. The objective of this study is to determine the effects of different levels of relative humidity (RH), air temperature (Ta) and effective clothing insulation on thermal comfort conditions from the exergy point of view. The performed analyses take into consideration the available data from the study by Toftum et al. (1998). The effect of different levels of RH, Ta and effective clothing insulation on human body exergy balance chain, changes in human body exergy consumption rate (hbExCr) and predicted mean vote (PMV) index were analyzed. The results show that thermal comfort conditions do not always result in lower hbExCr as it was proven in previous studies. Variations in effective clothing insulation, Ta and RH affect individual parts of human body exergy balance chain with an important effect on hbExCr. At hot and dry conditions the hbExCr is the largest while at hot and humid conditions it is the minimal. Hot and dry and cold and dry conditions have similar hbExCr. The difference appears, if the whole human body exergy balance chain is taken into consideration. To maintain comfortable conditions it is important that exergy consumption and stored exergy are at optimal values with a rational combination of exergy input and output.

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.
Simulation of energy use, human thermal comfort and office work performance in buildings with moderately drifting operative temperatures

Annual primary energy use in a central module of an office building consisting of two offices separated with a corridor was estimated by means of dynamic computer simulations. The simulations were conducted for conventional all-air VAV ventilation system and thermo active building system (TABS) supplemented with CAV ventilation. Simulations comprised moderate, hot-dry and hot-humid climate. Heavy and light wall construction and two orientations of the building (east–west and north–south) were considered. Besides the energy use, also capability of examined systems to keep a certain level of thermal comfort was examined. The results showed that with the moderate climate, the TABS decreased the primary energy use by about 16% as compared with the VAV. With hot-humid climate, the portion of the primary energy saved by TABS was ca. 50% even with the supply air dehumidification taken into account. The TABS working in a moderate climate kept the predicted percentage of dissatisfied (PPD) 10%; 1.4% in comparison to 17.5% h/yr. The highest estimated loss of occupants’ productivity related to their thermal sensation hasn’t exceeded 1% in whole year average.

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Subjective thermal sensation and human body exergy consumption rate: analysis and correlation

The exergy approach to design and operation of climate conditioning systems is relatively well established, while its exploitation in connection to human perception of the indoor environment is relatively rare. As a building should provide healthy and comfortable environment for its occupants, it is reasonable to consider both the exergy flows in building and those within the human body. There is a need to verify the human-body exergy model with the Thermal-Sensation (TS) response of subjects exposed to different combinations of indoor climate parameters (temperature, humidity, etc.). First results available on the relation between human-body exergy consumption rates and subjectively assessed thermal sensation showed that the minimum human body exergy consumption rate is associated with thermal sensation votes close to thermal neutrality, tending to slightly cool side of thermal sensation. By applying the exergy concept to the built indoor environment, additional results are going to be explored. By using the data available so far of operative temperature (to), the human body exergy consumption rates increase as to increases above 24°C or decreases below 22°C at relative humidity (RH) lower than 50%. While, at 85% of RH, the human-body exergy consumption rates decrease when to is increasing above 24 °C.

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An investigation on the assessed thermal sensation and human body exergy consumption rate
The exergy concept helps to optimize indoor climate conditioning systems to meet the requirements of sustainable building design. While the exergy approach to design and operation of indoor climate conditioning systems is relatively well established, its exploitation in connection to human perception of the indoor environment is rare. As the building should provide healthy and comfortable environment for its occupants, it is reasonable to consider both the exergy flows in the building and within the human body. A relatively new approach of the relation between the exergy concept and the built-environment research has been explored in the present work. The relationship of subjectively assessed thermal sensation data, from earlier thermal comfort studies, to the calculated human-body exergy consumption has been analysed. The results show that the minimum human body exergy consumption rate was related to the thermal sensation votes close to thermal neutrality, tending to the slightly cool side.

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 and 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.
Influence on Occupant Responses of Behavioral Modification of Clothing Insulation in Nonsteady Thermal Environments (RP-1269)

This paper presents climate chamber experiment results in which subjects were exposed to increasing and decreasing dynamic temperature drifts while being allowed to adjust their clothing insulation as desired. The objective of the study was to substantiate the scientific basis of the recommendations on drifting temperatures as stated in ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy (ASHRAE 2004) and to extend the scope of the recommendations to cover not only thermal comfort, but also the perception of air quality, health, and performance. The experiments addressed both the summer and winter comfort ranges of temperature, and subjects were exposed to rates of temperature change of -1.2 K/h (-2.2 degrees F/h), 0 K/h (0 degrees F/h), 1.2 K/h (2.2 degrees F/h), and 2.4 K/h (4.3 degrees F/h). Exposure duration was 4 h, except for the 2.4 K/h (4.3 degrees F/h) condition when it was 2 h. Thermal sensation responses observed with adjustable clothing insulation did not differ from those observed with fixed clothing insulation, which were reported in an earlier paper. However, with fixed clothing insulation, longer exposures (>4 h) seemed to aggravate general sick-building syndrome (SBS) symptoms, an effect that was not observed with adjustable clothing insulation. In addition, the study did not detect any systematic influence on the performance of operative temperature ramps, regardless of the clothing adjustment opportunity. Although the current study focused on thermal comfort and SBS symptoms and performance, the recommendations on drifting temperatures, as stated in ASHRAE Standard 55 (ASHRAE 2004), were generally verified. But, longer exposures to increasing temperatures may increase the intensity of general SBS symptoms when no opportunity to adjust clothing insulation is available.
Influence on occupant responses of behavioral modification of clothing insulation in non-steady thermal environments

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Occupant Responses and Office Work Performance in Environments with Moderately Drifting Operative Temperatures (RP-1269)

Fifty-two experimental subjects (50% female) were seated in a climate chamber and exposed to operative temperature ramps with different slopes, directions, and durations during two related experiments. The first experiment covered a temperature range of 22°C–26.8°C (71.6°F–80.2°F) and subjects wore light clothing (0.5 clo). The operative temperature was increased in rates of 0.6 K/h (1.1°F/h) (for 8 h), 1.2 K/h (2.2°F/h) (for 4 h), 2.4 K/h (4.3°F/h) (for 2 h), and 4.8 K/h (8.6°F/h) (for 1 h), respectively. In one session, subjects were exposed to a constant temperature of 24.4°C (75.9°F) (for 4 h).

The second experiment covered a temperature range of 17.8°C–25°C (64°F–77°F), and subjects wore heavier clothing (0.7 clo). Temperature ramps of 0.6 K/h (1.1°F/h) (for 8 h), 1.2 K/h (2.2°F/h) (for 6 h), 0.6 K/h (–1.1°F/h) (for 8 h), and –1.2 K/h (–2.2°F/h) (for 6 h) and exposure to a constant temperature of 21.4°C (70.5°F) (for 6 h) were examined. Subjects assessed their thermal sensation, acceptability of the thermal environment, perceived air quality, and intensity of sick building syndrome (SBS) symptoms. Subjects’ performance was measured by simulated office work, including tasks such as addition, proofreading, reading and comprehension, and text typing. Results of the experiments showed that even moderately changing operative temperature ramps were sensed by sedentary subjects when exposure times exceeded 4 h. No significant effects on SBS symptoms related to local irritation of mucous membranes were found, while intensity of headache, concentration ability, and general well-being were significantly affected in most of the ramps. Linear dependence of perceived air quality on operative temperature was noted. No significantly consistent effects of individual temperature ramps on office work performance were found.
Simulated performance of the Thermo Active Building System (TABS) with respect to the provided thermal comfort and primary energy use

The central module of an office building conditioned by a Thermo Active Building System (TABS) coupled with constant volume ventilation was evaluated by means of dynamic computer simulations. Additionally, the same building model was simulated with a conventional all air VAV ventilation system for comparison. The results showed that with the moderate climate, the TABS decreased the primary energy use by about 16% as compared with the VAV. With hot-humid climate, the portion of the primary energy saved by TABS was ca. 50% even with the supply air dehumidification taken into account. The TABS working in a moderate climate kept the Predicted Percentage of Dissatisfied (PPD) 10%; 1.4% in comparison to 17.5% hours/year.

Declaration of the High Tatras

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Simulated performance of the Thermo Active Building System (TABS) with respect to the provided thermal comfort and primary energy use

The central module of an office building conditioned by a Thermo Active Building System (TABS) coupled with constant volume ventilation was evaluated by means of dynamic computer simulations. Additionally, the same building model was simulated with a conventional all air VAV ventilation system for comparison. The results showed that with the moderate climate, the TABS decreased the primary energy use by about 16% as compared with the VAV. With hot-humid climate, the portion of the primary energy saved by TABS was ca. 50% even with the supply air dehumidification taken into account. The TABS working in a moderate climate kept the Predicted Percentage of Dissatisfied (PPD) 10%; 1.4% in comparison to 17.5% hours/year.

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Declaration of the High Tatras

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Human subjects’ perception of indoor environment and their office work performance during exposures to moderate operative temperature ramps

The objective of the presented research work was to study the effects of moderate operative temperature drifts on human thermal comfort, perceived air quality, intensity of SBS symptoms and office work performance. Experimental subjects (52, 50% female) were seated in a climatic chamber and exposed to operative temperature ramps (±0.6 K/h, ±1.2 K/h, +2.4 K/h, +4.8 K/h) of different direction and duration. The studied temperature ranges were 22-26.8°C (light clothing - 0.5 clo) and 17.8-25°C (heavier clothing - 0.7 clo). Exposure to steady temperatures (24.4, 21.4°C) corresponding to a neutral thermal sensation was also included. Subjects filled out questionnaires regarding perception of the environment and intensity of SBS symptoms. Subjects performed simulated office tasks (addition, text typing, proof reading, comprehension and reasoning). Results showed that all tested ramps were recognized by sedentary subjects when the exposure time exceeded four hours. No significant effect on SBS symptoms related to local irritation of mucous membranes was found, while intensity of headache, well feeling and concentration ability was significantly higher at the end of the exposure to the temperature ramps. A linear relation between perceived air quality and temperature (enthalpy) was found. No significant consistent effect of individual temperature ramps on office work performance was found. Increasing operative temperature appeared to slightly decrease speed of addition and text typing regardless the slope of the ramp, when compared to constant temperature condition. With respect to mentioned results it can be recommended to avoid ramp with slopes equal or above 1.1°C/0.25h. Spaces where temperature ramps occur should be properly ventilated to avoid further increase of SBS symptoms caused by aggravation of perceived air quality. Increasing temperature may negatively influence speed of simple, repetitive tasks of mental work. The significant effect on complex tasks that require concentration, vigilance and logical thinking was not found.

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Occupant responses and energy use in buildings with moderately drifting temperatures

Earlier studies conducted in climate chambers have examined a large range of temperature ramps from 0.5 K/h to 5 K/h (0.9°F/h to 9°F/h), but their focus was mostly on establishing temperature limits for acceptable thermal comfort with non-steady-state temperatures. Thus, when this ASHRAE funded research was initiated in 2005 knowledge was lacking on how the intensity of building related symptoms, the perception of air quality and the performance of office work were affected by exposure to non-steady-state temperatures. ASHRAE Standard 55 (2004) provides recommendations for maximum rates of temperature change to avoid discomfort, but these recommendations are based mostly on engineering judgment and to some extent on results of earlier thermal comfort research. New approaches to reducing the consumption of energy for climate conditioning in buildings are often associated with indoor temperatures that drift somewhat during the day, and there was a need to extend the scope of the recommendations to cover not only thermal comfort, but also health and productivity. The aim of the proposed research was to carry out human subject experiments and field observations to validate the scientific basis of the recommendations on non-steady-state temperatures as stated in Standard 55 and to evaluate how Sick Building Syndrome symptoms, perceived air quality and performance are affected by such changing temperatures. In addition, the feasibility of non-steady-state temperatures as a means of energy savings and reduction of installed HVAC system capacity was evaluated by dynamic simulation of building energy consumption and indoor environment, taking into account potential effects on occupants of such non-steady thermal environments. Several building HVAC configurations and locations with different outdoor climate conditions were simulated. Two different approaches were used in the human subject experiments; a) exposure of human subjects to temperature ramps with fixed clothing insulation and b) with subjects being allowed to adjust their clothing insulation as desired. In the former experiments, subjects’ thermal sensation was expected to vary along with the drifting temperature, as a basis for the most conservative limits to design temperatures and their maximum permitted rate of change, while in the latter experiments, thermal sensations were expected to remain more stable, justifying wider temperature limits. Experiments covered short-term exposures (1 and 2 hrs) at high rates of temperature change as well as moderate to long-term exposures (4 and 8 hrs) at modest and low rates of temperature change. Temperature ramps spanned the summer and winter comfort ranges of temperature. The experiments were designed to address not only thermal comfort but also to determine whether a range of human symptoms would be affected by increasing and decreasing temperature ramps, and to quantify their effects on the performance of typical office tasks.