Conference Agenda

15th ROOMVENT Conference

Session

VM: Ventilation measurement techniques

Session Chair: **Douaa Khoder Al Assaad**

Presentations

Multi-stability of the large-scale circulation in turbulent mixed convection measured in a small-scale room ventilation model

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We report on experimental evidence of multi-stable large-scale circulation (LSC) in turbulent mixed convection in passenger cabins. The large-scale flow structure are mainly responsible for thermal comfort and pollutant distribution. Coexisting LSC can cause insufficient ventilation situations due to the hysteresis-effect, which is a main feature of this multi-stability. We perform our experiments in a small-scale model room with a passenger cabin like shape, which has four heated obstacles at the bottom and inlets and outlets at top and bottom, respectively. The model room has a height of H=0.3m, a length of L=0.4m and a depth of D=0.5m and is made of Plexiglas. We are using a 2D2C-PIV System to investigate the velocity field within one cross-section (Fig.1) while varying the boundary conditions. The boundary conditions are the inlet flow velocity and the global temperature difference between the heated obstacles and the cool inlet flow. The working fluid we use for our experiments is dry air and sulfur hexafluoride (SF6). Due to an isothermal variation of the pressure of the working gases, we are able to reach values of Rayleigh number and Reynolds number reasonable for indoor airflow ventilation situations in passenger cabins. For that purpose we use the SCALEX-facility (Fig.2), which consists of a pressure vessel with the model room inside and the working gas supply. From the outside we apply the 2D2C-PIV system. We found three different LSC-Structures which correlate with an increasing Archimedes number, while keeping Rayleigh number constant. When increasing the Archimedes number the LSC transforms from a 2d two-role system dominated by forced convection to a complex 3d one-role system to a quasi-2d one-role-system. The range where the transition between these flow structures occur depend on the history of the Archimedes number. Moreover, we found also a dependency of these transitions on the Rayleigh number, i.e. the critical Archimedes number is not constant.

Dynamic Steady State Concentration Distribution Realized in Air Recirculating Systems with Air Leakage Part 1 Theoretical Consideration

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The tracer gas experiment method has not been established when evaluating the effect of air conditioners without ventilation or air purification devices using air recirculation. This is because when the tracer gas is supplied in such an air recirculation system, the indoor concentration rises without limit and a steady concentration distribution cannot be obtained. In this study, we have theoretically examined the method of measuring the ventilation efficiency of a ventilator under such conditions. Since the concentration distribution is a linear phenomenon, it is used that if there is a pollution source in the room and there is a negative generation source that cancels the contamination in the recirculation part, an equivalent concentration distribution in an open air system can be obtained. In the actual experiment, a tracer gas experiment is performed in the case where an indoor source and a recirculation part source exist independently, and a steady concentration distribution is obtained by adding the experimental results. It shows that the concentration distribution in the case of the recirculation part source alone corresponds to the age of air distribution. It is shown that even if there is air leakage in the air recirculation system, the concentration will become steady after a sufficient time has elapsed, but the sum of the concentrations of the indoor source and the recirculation source alone after a certain elapsed time after the start of the experiment will be the steady concentration. In addition, the concentration distribution in the case of the circulation source immediately after the start of the experiment shows that the result approximates the age of air in the case of no air leakage. These theoretical examinations are verified by numerical simulation using CFD.

Comparison of Temperature Measurements by Wired and Wireless Room Temperature Sensors

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Accurate measurement of indoor temperature is vital for the control of heating, ventilation and cooling (HVAC) systems to provide thermal comfort for occupants. Thermostats are installed for this purpose. However, the conventional placement of thermostats on walls is likely to cause discrepancies between the occupants' thermal needs and supply from the HVAC system. The implementation of wireless sensors as the temperature sensing component of the thermostat in the building management system has the potential of overcoming such issues. Thus, it is necessary to compare the measurement behavior of room temperature sensors in relation to their position and each individual product characteristics. In addition, with the growing number of buildings with radiant heating and cooling systems, it is appropriate to examine the effect of the HVAC type on the temperature measurement as well, as radiant and all-air systems have different passages of transferring heat to or from indoor spaces.

In this study, a comparison of seven wireless and four wired temperature sensors (all available on the market) was conducted in a test chamber with a two-person office setup and a heated surface simulating a window. Measurements were conducted under both radiant and all-air cooling systems, each with two levels of cooling load (high and low). Sensors were placed in a total of seven positions, varying the location and height. Each of the sensor measurements were compared with a reference air and globe temperature at the same position to determine its accuracy. Results show that the position and load condition had a larger effect on the temperature distribution within the room and measurement differences than the cooling system type. Among the sensors under the same condition, different measurement tendencies were seen. For instance, some measured close to the globe temperature while others measured close to the air temperature. What a specific sensor measures close to (either air or globe temperature) should be identified beforehand by manufacturers. It is also suggested that room temperature sensors and thermostats should be positioned near the occupants instead of being installed on the wall.

Evaluating Building Leakage Characteristics for Single-family Dwelling Stock

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The objective of this paper was to determine a method for the evaluation of leakage characteristics related to the building airtightness of wooden single-family dwellings. Leakage modeling of component openings made from the leakage characteristics (relationship between air flow rate and pressure difference) of rooms and buildings were compared with measurements. Rooms or buildings can be considered as networks of openings that can be combined either in series or in parallel. An exponential equation, commonly known as the power law, has often been used for building envelope openings. We propose the parallel combination model in which narrow openings with low Reynolds numbers (e.g. adventitious openings – cracks in walls, etc.) and large openings (e.g. purpose-provided openings – air inlet, etc.) are assumed to exist in parallel. The parallel combination model had precision equal to or better than the power law in terms of suitability with measured values. In addition, the effective leakage area per floor area at 9.8 Pa (ELA_{F10}) of the panel-type thermal insulation method was, in general, less than 1.0 cm^2/m^2, indicating high airtightness. In houses about 5 to 10 years after construction, the air permeability slightly increased in four out of eight wooden houses.

An experimental comparison between different methods to measure building natural ventilation

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The energy performance of buildings represents a main technical goal in building sector. To this end, European Union established specific measures to improve the energy efficiency of buildings by means of the Energy Performance of Buildings Directive which introduced the nearly zero energy buildings (NZEBs) as the new building target. In addition to the energy performance, a further aspect to be considered in the NZEB design is the indoor environmental quality (IEQ) which is strictly related to both the indoor thermo-hygrometric parameters (thermal comfort) and the building ventilation (indoor air quality) and, consequently, it also affects the energy performance of the building. This is even more important in NZEBs as they are characterized by ventilation losses quite comparable to the transmission losses: thus, it is essential characterizing accurately the air permeability and the actual air exchange rate of the building.

Two different standards are currently available to measure the air permeability and the air exchange rate of the buildings, respectively. The air permeability is measured through the pressurization method (Blower Door Test, BDT) described by the standard ISO 9972:2015. Such method is based on the generation of pressure differences across the building envelope higher than those reachable under normal weather conditions, thus the measurement of the resulting airflows allow to determine airtightness of the envelope. Therefore, the results provided by the BDT are not affected by the weather conditions, nonetheless they don't provide the actual air exchange rate. On the contrary, the air exchange rate is measured according the tracer gas decay method defined by the ISO 12569:2017 standard which provides, unlike BDT, the air exchange rate under the specific weather conditions detected during the tests.

Several studies attempted to find out a correlation between the information provided by the two methods: this correlation would allow estimating the actual air exchange rate of the building under different weather conditions just on the basis of an air permeability measurement (as it is extremely repeatable by definition). Unfortunately, to date, no wide-ranging correlations where carried out by the scientific literature.

The paper is focused on the comparison of the two abovementioned methods. To this aim, an experimental analysis was carried out in a dwelling located in the Central-South Italy and air permeability and air exchange rate measurements, both in the whole dwelling and in parts of it, were performed. The results demonstrate that the pressurization test carried out on the whole dwelling do not allow to identify possible air permeability gradients within the envelope. Moreover, the influence of the outdoor microclimatic conditions on the actual air exchange rate were investigated and quantified. Finally, the criticalities related to the correlation of air permeability and air exchange rate data were highlighted and stressed.

A Platform for Visualizing Building Indoor Environment Flow Field Features

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In the present paper the implementation of a platform is described making available the visualization of complex numerical fluid dynamic simulation results to any professional involved in the building design and management. Real-time performance is achieved, the fluid dynamic field being investigated by means of the so-called Fast Fluid Dynamics (FFD). The platform addresses the issue concerning the numerical model results interpretation, currently prerogative of experts. An Augmented Reality visualization tool is implemented and integrated into the platform for democratizing the results comprehension. A meaningful overview of the power of the technique is provided by overlapping typical fluid dynamic features to images grabbed in a real office room.

Investigation of Unsteady Ventilation with Particle Image Velocimetry (PIV)

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The effects of different unsteady ventilation strategies on flow-structures in a room are investigated and compared to steady ventilation with the same mean exchange rate. For this, whole-field optical flow measurements were executed by means of a particle image velocimetry system (PIV) in a Reynolds-scaled room model in water. In a first series of experiments, sinusoidal varied supply flows with different frequencies were analysed; two equally supplied simple nozzles in the ceiling were used as inlets. The setup was validated by comparing jet velocities with literature values.

Typically, room airflows are investigated with punctual measurement techniques (e.g. anemometers), which have an impact on the flow field, or with smoke gas experiments. By using PIV, the flow can be analysed without any influence of sensors or stands/traverses and whole-field measurement data with high spatial resolution and detailed information on the flow field can be collected.

Local and time-averaged velocities and standard deviations were calculated for all scenarios. Unsteady conditions were created by a sinusoidal variation of the supply flow rate with frequencies between 0.025 s^{-1} and 0.050 s^{-1}, an offset of about 1.1 m^3/h (3.056×10^{-4} m^3/s), and an amplitude of about ±1.0 m^3/h (2.778×10^{-4} m^3/s), which leads to a mean exchange rate of 3.5 h^{-1}. Although averaged velocity fields only show slight differences between steady and unsteady conditions, single pictures vary widely. First effects of unsteady ventilation on flow structures can be recognized. Steady structures are destroyed, and velocities change rapidly.

The inlets will be changed to small-scale ceiling-diffusors in future experiments to create more realistic room ventilation conditions. Other types of unsteady supply flows will be implemented, and parameters will be varied. The results of the PIV-measurements can be used to validate CFD simulations and to derive dimensioning rules and application recommendations.

Gas traces techniques for airflow characterization in double skin facades

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The monitoring of fluid dynamics of ventilated cavities is a challenging part of the thermo-physical performance characterization of double skin facades (DSF). Tracer gas techniques are non-intrusive methods to determinate the bulk airflow rate inside ventilated cavities, even if only for short periods. Continuous monitoring of fluid dynamics behavior (through measured velocity or bulk airflow) is sometimes needed, and gas tracer techniques can be therefore used as primary measurement principle to which other measurement methods, more suitable for continuous monitoring, can be referenced.

In this paper, we present the characterization through gas tracer techniques of the mechanically induced airflow in the cavity of double skin façade, and we correlate the values measured though these methods to those obtained through the velocity profile method. The preliminary results presented in the paper allow to have a first insight on how two gas tracer techniques compare and correlate to airflow estimation though direct velocity values reading, showing the challenges associated to these methods and possible explanations for challenges in ensuring a robust correlation between the different measurement techniques.

Reconstruction of the indoor air temperature distribution using acoustic travel-time tomography

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Acoustic travel-time tomography (ATOM) is being increasingly considered recently as a remote sensing methodology to determine the indoor air temperatures distribution. It employs the relationship between the sound velocities along sound-paths and their related travel-times through measured room-impulse-response (RIR). Thus, the precise travel-time estimation is of critical importance which can be performed by applying an analysis time-window method. In this study, multiple analysis time-windows with different lengths are proposed to overcome the challenge of accurate detection of the travel-times at RIR. Hence, the ATOM-temperatures distribution has been measured at the climate chamber lab of the Bauhaus-University Weimar. As a benchmark, the temperatures of NTC thermistors are compared to the reconstructed temperatures derived from the ATOM technique illustrating this technique can be a reliable substitute for traditional thermal sensors. The numerical results indicate that the selection of an appropriate analysis time-window significantly enhances the accuracy of the reconstructed temperatures distribution.

Dynamic Steady State Concentration Distribution Realized in Air Recirculating Systems with Leakage Part 2 Experimental verification

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In the previous report, the theoretical consideration about the tracer gas experiment in the air circulation system without ventilation was described. This study is an experimental verification of the theory discussed in the previous report using our laboratory. As stated in the theory of the previous report, in the actual experiment, a steady concentration distribution is obtained by adding the experimental results of the air circulation system. Then, confirm that the result corresponds to an equivalent open system. In addition, the validity of the theory is verified by examining the correspondence between the circulation source immediately after the start of the experiment and the age of air when there is no air leakage. In the tracer gas experiment of this study, the consistency between the case without air leakage and the case with air leakage is confirmed. Furthermore, detailed case division is performed according to the occurrence position and the presence or absence of a blower. As an experimental procedure, first, it is confirmed that the theory holds true when there is no leakage. Next, in the case of leakage, we consider that the theory can be applied in both cases of synthesis at an early time when there is not much influence of leakage and synthesis at a later time when there is influence of leakage. At the same time, in the synthesis at an early time, it is also confirmed that the generation of the circulation system and the age of the air when there is no leakage show a good correspondence.

Improvement Method of Thermal Environmental Near Windows During Heating Period - Outlet Characteristics and CFD Modelling Method of the Slot Line Diffuser

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The perimeter space near the windows usually has some problems in the thermal environment which is easily affected by heat transfer and radiation from windows. And the airflow in this area usually has different characteristics compared to the interior of the room due to the effect of buoyancy or cold draft in winters. To improve the environment of the perimeter space, the slot line diffusers are widely used in Japan as the terminal equipment of air conditioning and ventilation system. In this research, two deflection panels are installed inside of the slot line diffuser to decrease the outlet area and increase the outlet airflow wind speed for improving the heating effect. The heating performance of the slot line diffuser was examined by

experiment and a detailed CFD (Computational Fluid Dynamics) simulation. By means of CFD, the velocity distribution of the outlet airflow near the diffuser was predicted based on detailed meshes. The relations between outlet velocity, outlet distance and temperature are examined.

For the experiment, the slot line diffuser is set up in a free field, the air supply temperature and the outlet area are adjusted as parameters. The temperature and velocity at diffuser's outlet space were movements measured by an ultrasonic anemometer and thermocouple with a traverse system to obtain the distribution of heating airflow jet from the diffuser. The outlet velocity (components of X, Y, Z) and outlet temperature were also measured by a hotwire anemometer in high frequency (1000Hz), used as the boundary condition of a detailed CFD model of the slot line diffuser.

The accuracy of this CFD simulation of the heating outlet airflow by using the detailed model was examined. Then the velocity of the heating airflow was calculated at different distances from the diffuser. The CFD simulation was carried on in several temperature conditions to examine the relations between the outlet temperature and the throw of the hot airflow.

Based on the relations between outlet temperature and airflow velocity distribution, the location of boundary conditions (control surface) for the P.V. method (Prescribed Velocity Method) of the slot line diffuser was decided. Finally, the model of the slot line diffuser by the P.V. method is presented in this study, based on the results of a detailed simulation.

Dynamic infiltration airflow rate measurement thanks to tracer gas method : a case study at a dwelling scale.

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This study has been undertaken in the context of the evaluation of intrinsic thermal performance of building envelope. These methods usually use a calibration process that gives for a recorded data set (weather data, internal temperature, heating and cooling load, …) and a simplified RC model the corresponding model parameters. Thus from these parameters thermal characteristics such as the U-value could be deduced. To separate the U-value from the infiltration in this identification process, it is important to dynamically model the infiltration airflow.

To achieve this last point, an experimental campaign has been setup in a real size house to measure the dynamic infiltration airflow rate. For that, a tracer gas method has been used and more specifically the method of constant gas injection. The objective of this paper is to present the setup and results of this experimental campaign and a comparison between usual calculation technics.

The campaign has been setup in an experimental house of around 90m² on two levels. The tracer gas used is CO2 with 8 injection points (4 by level) and the method of constant dose injection was used. CO2 concentration is monitored every minute thanks to 9 sensors, and other sensors monitored ambient indoor air (temperature, relative humidity) in each room and outdoor conditions thanks to a weather station. The experiment has been run during 2.5 months in Q1 2020 in parallel of thermal scenarios stress, which aims to determine the thermal performance of the envelope. These thermal scenarios consist to heat the house with intermittent constant power sequence and a temperature upper limit set to 35°C.

Firstly, the results will include an analysis and discussion of the spatial distribution of both CO2 concentration and temperature. Then, thanks to the generated data, three different techniques to determine the infiltration rate will be compared including the rule of thumb, the method proposed by the LBNL in AHSRAE 119, and the one defined in the norm ISO12569. The second method uses the weather condition integrating the wind velocity and the temperature difference between the indoor and the outdoor. The last method uses the dynamic CO2 concentration measurement to estimate the infiltration flow rate. Finally, the impact of filtering data among different time steps (from one minute to one hour) will be analysed as well.