Project summary

The Refresh project team explored the impact of urban microclimate on building ventilation for optimal performance of occupants. We used a range of methods (measurements, wind-tunnel modelling, CFD, qualitative interviews, controlled EEG tests) across idealised and realistic buildings to understand better how we respond to poor air quality, and how natural ventilation can help to improve it. The project ran from 2013-19 and was led by Prof Janet Barlow (University of Reading), Prof Cath Noakes (University of Leeds) and Prof m c schraefel (University of Southampton). It was funded by EPSRC under the Challenging Engineering scheme.

Building-microclimate interactions

University of Reading researchers completed the Refresh Cube Campaign (RCC) at Silsoe, UK, in collaboration with the University of Birmingham. It was the first field study of natural ventilation for an idealised array of cubical "buildings" under realistic weather conditions. Engineering standards often include design data for isolated cubical buildings, which motivated the experiment. The 9 month-long experiment used haybales stacked as cubes to represent buildings surrounding an instrumented test building where ventilation was measured. Pressure coefficients on the buildings were also modelled at the EnFlo wind tunnel laboratory at the University of Surrey. The University of Leeds validated different CFD models against the RCC data and investigated flow around the buildings and its effect on ventilation. Findings were:

On ventilation, models and engineering standards

- Cross ventilation rate for the array case was reduced by 50-90% compared to the isolated building when the wind was within ± 50° of being perpendicular to the window. [1]
- Single-sided ventilation models, commonly used for design, underestimate the RCC field data by a factor of 10-20. Levels of turbulence are much higher for the RCC experiments than previous work – results suggest that turbulence can enhance ventilation rate when window size is relatively small (1% of wall area). This is a typical situation for buildings in dense urban areas. [4]
- CFD simulation using OpenFoam (LES) and Fluent (RANS) compared reasonably well with RCC data and CIBSE standards in terms of pressure coefficients. Ventilation rates agreed within the spread of the RCC data, with cross ventilation easier to predict than single-sided. [5]

- When comparing traditional methods of ventilation measurements, tracer gas results underestimate compared to pressure-based results. This is more the case for single-sided ventilation than cross ventilation and is dependent on wind direction. [2]
- Pressure coefficients from wind-tunnel, CFD data and engineering standards data tended to underestimate the full-scale RCC test cube data. For the array case, RCC results did not agree with the standard data for individual building facets as the building layout is asymmetrical. However, the data for the pressure drop across the building agreed better. [3]

On microclimate and flow

- Flow patterns around a building surrounded by buildings (the “array case”) can switch between different states for the same background wind direction. This is due to complex interactions between building wakes and can lead to errors in predicted ventilation rates. [1]
- Unsteady CFD simulations showed that an internal jet appeared for most wind angles for cross ventilation for the isolated building. For the array case, the internal jet was very weak; however, internal mixing seemed to be improved by the influence of unsteady flow outside the window. [5]
- CFD simulation using a lattice-Boltzmann method (LBM) running on a GPU showed good agreement with Fluent simulations and RCC data. As LBM simulations are almost 10,000 times quicker, this shows promise for real-time flow simulation in the future which will aid building design. [6]

Human-building interactions

Work was done by the University of Southampton on how people respond to poor indoor air quality (IAQ), and how technology could help them. A study was done to understand the social determinants of Indoor Environmental Quality in offices by conducting semi-structured interviews with occupants.

- Office environments were identified by occupants as being poor sometimes (ie too hot/cold, stuffy). Adjustments to windows, thermostats, radiators were made through negotiation with others, especially those who “owned” windows by sitting next to them. Other “gate-keepers” included building managers who adjusted the environment heating or ventilation. [7]

A controlled experiment, testing the effect of “fresh” (low CO_2 concentrations) and “stale” air (high CO_2 concentrations) on cognitive performance, was done at the University of Southampton. EEG was used to monitor brain state and was as an objective measure of sleepiness. Other physiological, psychological and Sick Building Syndrome factors were also monitored.

- Cognitive performance was affected even after short exposures (<40 minutes) to high CO_2, more so in people who were already sleepy. As there was no other measurable effect on participants, this suggests that poor indoor air quality can impact cognitive performance of office-workers prior to them being aware of it. IAQ feedback displays could assist people in changing their work environment for the better. [8]

A device recording and displaying CO_2 and relative humidity levels ("The Aether") was designed and trialled in offices. Based on the finding that IEQ is partly socially negotiated, the device needed to be visible to all – a "situated technology", like a clock on the wall.

- A simple IAQ feedback device achieved straightforward sense-making, where participants understood the relationship between its readings, air quality, and the need to ventilate the room. Positive design features were its focus on only one indoor pollutant (CO_2) and its minimal cues (simple traffic light display colours). [9]

How can our findings be used?

Ventilation results are of potential interest to engineering consultants, architects and building service engineers who design ventilation systems for buildings or building layout/design in city redevelopment plans. Results will also be of interest to emergency responders in the case of contaminant ingress in buildings. Human-Building Interaction results are of interest to Human Computer Interaction practitioners and occupants and building managers making the most of existing buildings.

References

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