Multi-Criteria Evaluation of Eight Ventilation Systems in Renovated Houses: Energy, Air Quality and Comfort Performance

Nolwenn Hurel (on behalf of the JUSTAIR Team)

Cerema, BPE Research Team
46 rue Saint Théobald
38081, L'Isle d'Abeau, France

ABSTRACT

In the renovation of single-family homes, ventilation is often overlooked: there is no regulatory obligation to upgrade it, and installing mechanical ventilation in existing buildings can be difficult or costly. Yet renovated homes often reach high airtightness, making indoor air quality (IAQ) strongly dependent on mechanical systems. This poses health and comfort risks and highlights the need for guidance. In France, the ongoing research project JUSTAIR addresses this by assessing the performance of ventilation systems for low-energy retrofitted dwellings. A multi-criteria approach compares systems not only for IAQ and energy use, but also thermal, acoustic, and olfactory comfort, and cost. Eight systems were evaluated, including very common ones and others less widespread but sometimes used in renovation due to installation and cost constraints: balanced ventilation with heat recovery (BV), thermodynamic BV, single-exhaust humidity-based systems (EV-rh a/b), supply-based (SV), decentralized mechanical balanced ventilation (DBV), BV without supply ducts (BV-nsd), and distributed mechanical ventilation (DEV).

The study relies on a coupled CONTAM–TRNSYS model representing airflow, pollutant transport, and thermal behaviour. Three of the less widespread systems (SV, BV-nsd, DBV) were first experimentally tested in the INCA experimental house. The experimental data were used to calibrate and improve the numerical models. A parametric analysis then explored variations in occupancy, emissions, outdoor pollution, insulation and airtightness, climate, and window-opening behaviour, enabling harmonised comparisons across indicators for CO_2, humidity, formaldehyde, PM2.5, NO_2, radon, airflow rates and directions, energy use, and summer and olfactory comfort.

Results show marked contrasts in winter. CO_2 performance depends more on window use and airtightness than on occupancy: BV achieves the best levels (ICONE <1.5, P95 <1500 ppm) due to higher airflow, while EV-rh and DEV systems show higher concentrations (ICONE >3, P95 ≈3000 ppm). SV is highly sensitive to openings, as supplied air tends to escape through nearby windows rather than circulate through rooms to outlets. Humidity is better controlled by EV-rh systems regarding time outside 40–60%, though periods >70% are similar across systems. Formaldehyde exposure roughly doubles for EV-rh and DEV, mainly driven by emissions and window management. PM2.5 decreases by about one third with BV, whereas DEV performs worst with periods without ventilation rates. NO_2 depends mainly on outdoor levels, with similar exposure across systems. Radon is best mitigated by SV and, to a lesser extent, BV.

In summer, IAQ improves overall, mainly because windows are opened more often: lower CO_2 peaks, reduced formaldehyde, and slight decreases in PM2.5, NO_2, and radon. Regarding fan consumption, EV-rh systems consume less due to lower fan flows on average. Summer discomfort depends more on window use, climate, and envelope performance than on ventilation. Odour removal is weakest for DEV (periods without airflow) and partly for SV (air outlets less efficient than exhausts), while acoustic comfort is acceptable except at high DBV speeds.

This multi-criteria evaluation highlights trade-offs between IAQ, comfort, and energy, providing valuable guidance for ventilation choices in renovation contexts.

KEYWORDS

Ventilation, IAQ, numerical model, experimental measurements, parametric study