Effect of heat waves in PM indoor concentration and optimization of air flow rates in mixed-mode ventilated classrooms

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ABSTRACT

Heat waves are becoming increasingly frequent in southern Europe. They often occur during the school term, posing health risks on children and teachers and potentially impairing academic performance. Extreme heat and associated atmospheric conditions can increase outdoor particulate matter (PM) concentrations through atmospheric stagnation and enhanced secondary aerosol formation; these elevated outdoor PM levels may subsequently penetrate into indoor environments. Classrooms are commonly naturally ventilated through window opening, although in some cases constant air-volume mechanical ventilation systems are also installed. Indoor thermal comfort and PM concentration levels represent competing performance objectives, requiring adaptive ventilation control.

This study aims to design an automated mixed-mode ventilation strategy tailored to classroom-specific solar and wind exposure, window geometry and occupancy to maintain adequate thermal comfort and air quality, especially during extreme heat events. To this end, indoor variables (temperature, relative humidity, CO_2, $PM_{1.0}$, $PM_{2.5}$, PM_{10}) were monitored at 15-minute intervals in Madrid primary school classrooms using MICA PLUS instrumentation, while hourly meteorological outdoor data were obtained from a nearby weather station. EnergyPlus models were then developed using a pressure-based Airflow Network representing airflow through zones, openings, and mechanical components, accounting for wind, buoyancy, leakage, and interzonal flows. Models were calibrated against measured indoor temperature rates and statistically validated per IPMVP and ASHRAE Guideline 14-2023.

The calibrated models were employed in a multi-objective optimization using an evolutionary algorithm, with thermal comfort and indoor PM concentration as performance objectives, and natural and mechanical ventilation airflow rates as decision variables. The optimization results yielded a set of optimal ventilation programmes capable of reducing indoor pollutant levels while minimizing thermal stress in the classrooms.

KEYWORDS

Mixed-mode ventilation, PM concentration, Heat wave, Thermal comfort, Multi-objective optimization