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PASSIVE VENTILATION VIA ORIGAMI-DRIVEN STACK EFFECT IN COLD REGIONS

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ABSTRACT

Ventilation in cold regions presents significant challenges for achieving sustainable, low-energy building and infrastructure systems, often requiring energy-intensive solutions. In underground mining operations across Northern Canada, ventilation can constitute up to 50% of operating expenditures (OPEX). Similarly, remote communities seek low-cost, energy-efficient systems. This study introduces a novel passive ventilation concept driven by the stack effect and enhanced by origami-inspired structures. The proposed system utilizes a deployable extension made of stacked Kresling elements (SKE) retrofitted atop chimneys or exhaust ducts with little structural modification. These elements can expand or contract on demand, thereby modulating chimney height and controlling airflow rates with minimal energy input.

To evaluate system performance, we developed full-scale three-dimensional computational models based on the Reynolds-Averaged Navier–Stokes (RANS) equations, where buoyancy is governed by temperature-dependent air density (ideal gas model). The geometric intricacy of the stacked Kresling elements is fully integrated into the model to capture their effect on airflow dynamics. In parallel, an analytical model employing the first law of thermodynamics is derived to estimate ventilation rates as a function of indoor-outdoor temperature differentials. Various geometric configurations are explored, with a focus on the number of panels and the aspect ratio of individual elements.

Results show that integrating SKEs can significantly enhance and regulate ventilation. In cold-region scenarios with temperature differences exceeding 20 °C, doubling or tripling the duct height via SKEs leads to ventilation rate increases of approximately 30% and 50%, respectively. Owing to their tunable geometry, SKEs also offer high adaptability: a configuration with six panels and an aspect ratio of 0.75 can achieve a fivefold variation in ventilation rate between its fully expanded and contracted states. From a fluid dynamic perspective, increasing the element aspect ratio or number of panels reduces viscous forces in the airflow. In these low-friction scenarios, the ventilation rate can be reasonably approximated using the analytical model, particularly under low temperature differences.

Overall, this work demonstrates the potential of adaptive origami structures to passively regulate ventilation in cold climates, offering advantages for both mining and residential applications. Future research will focus on optimizing SKE geometry to minimize flow resistance and integrating the system with passive heat recovery ventilation—such as heat pipes—for combined thermal and airflow control.