Kirigami-inspired wind steering to cool sweltering urban canyons, improve ventilation

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Researchers at Princeton's engineering school have found that placing a specially designed lid over a box can dramatically increase the airflow

from wind blowing across the upper surface. It is not just a parlor trick. The information could help clean and cool urban canyons in cities like New York and Hong Kong and improve ventilation in popup restaurants and bus shelters.

In an article published Feb. 4 in the *Journal of Wind Engineering and Industrial Aerodynamics*, the researchers found that a cover with a row of evenly spaced, tilting slats, called louvers, can increase the airflow in a box by channeling wind that ordinarily would flow over the open top.

The researchers further modified the top's geometry using the Japanese art form kirigami. Like the paper folding of origami, kirigami artists cut paper and similar thin materials. The technique allowed the researchers to stretch and bend the cover in novel ways, which further increased the amount of air moving through the enclosure.

"If you cut the lid in a certain pattern and stretch it, it becomes three-dimensional," said Elie Bou-Zeid, a professor of civil and environmental engineering at Princeton and one of the lead researchers. "It can guide the flow of air to come in and out in ways that are better for ventilation than having no lid whatsoever."

Originally, Bou-Zeid said, the researchers were looking for a way to improve the popup venues that sprang up on city streets during the COVID pandemic. The small structures, which offered outdoor seating during COVID, often became stuffy when windows were closed. The researchers wanted to know if adjusting the roof could offer a solution.

"With an open top, the main flow pattern is circular, a vortex," Bou-Zeid said. "You do get some exchange of air near the top but most of the air spends a long time in the box."

Bou-Zeid's research has advanced the understanding of urban heating in

a warming climate. Among other topics, his work has described how cities' concrete buildings and paved roads often create heat islands that concentrate temperature during hot seasons.

For this project, Bou-Zeid worked with colleagues Sigrid Adriaenssens, an expert in construction involving adaptive, lightweight material; and Marcus Hultmark, who specializes in fluid dynamics and atmospheric modeling. The researchers wanted to know whether louvers could increase both air circulation and shade in urban canyons.

Lucia Stein-Montalvo, a postdoctoral researcher at Princeton and the article's first author, said the researchers began work by looking at how a traditional louver with a uniform row of tilting boards could adjust to affect air flow.

Stein-Montalvo, who is an expert in the solid mechanics of kirigami, and co-researcher Liuyang Ding designed a box and set of louvers from acrylic. They used the setup in a series of experiments in the wind tunnel at Princeton's Instructional Fluid Dynamics Laboratory. Along with computer simulations, the wind tunnel tests allowed the team to examine how the tilting boards changed the dynamics of the moving air.

As a next step, the researchers conducted the same simulations while altering the size, geometry and orientation of the louvers. They were able to create a system to adjust the louvers to maximize the air flow inside the box. They changed the orientation of the boards that made up the louver. Instead of a uniform row of boards, they created one that held boards of differing orientations.

Finally, the researchers used kirigami to reconfigure the geometry of the louvers. For the experiment, the researchers built a design in which the kirigami sheets warped into waves with crests rising smoothly from the lid's horizontal plane. The waves were spaced in echelon so that the

crests of one row were followed by a trough of the next.

When stretched over the box, the sheet resembled a honeycomb pattern. To create the kirigami cover, the researchers used a laser to cut the pattern from a 1-millimeter-thick plastic sheet. When they stretched the sheet and fastened it to the box, the kirigami created the test pattern.

Stein-Montalvo said the experiments' purpose was to define some of the physics that governed the air movement. That allowed the researchers to improve the simulations, which were checked and further improved by the wind-tunnel experiments.

Eventually, the improved simulations allowed the researchers to evaluate the interaction between kirigami and fluid flow in planes that would have been difficult to observe in experiments. She said future projects will begin to look at patterns and materials that could be deployed in cities and structures.

"We used this paper to show that we can use kirigami and that it works. But there is room for optimization," she said. "In the next paper, we will be thinking about more realistic settings like urban canyons. I am also thinking about materials at large scale and about structural stability."

More information: Lucia Stein-Montalvo et al, Kirigami-inspired wind steering for natural ventilation, *Journal of Wind Engineering and Industrial Aerodynamics* (2024). DOI: 10.1016/j.jweia.2024.105667

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