Window Design and the Design of Air Flow

Worre Foged, Isak; Barbotin, Alexis

Published in:
PLEA 2020 - Planning Post Carbon Cities

DOI:
10.17979/spudc.9788497497947

Publication date:
2020

Document Version:
Publisher's PDF, also known as Version of record

PLEA 2020 A CORUÑA

Planning Post Carbon Cities

Window Design and the Design of Air Flow

Simulation Studies Revealing How Windows Form Air Movement

Isak Worre Foged, Alexis Barbotin

Aalborg University, Aalborg, Denmark

This study examines window designs and the design of airflow through the movements of sliding and rotational elements of the windows. Nine different window types are parametrically modelled and paired with a computer fluid dynamics simulation of the airflow velocity and airflow patterns. Both of these aspects being important parts in determining and creating thermal sensations in buildings. Each window design is studied at ten different opening percentages and then assessed through a comparative analysis, registering maximum, minimum and averages velocities, and the specific abilities to steer airflow as an instrumental technique in thermal design. The studies find that the Vertical Pivot window performs best considering air velocity generation and air flow steering, thereby enabling designers to utilise air as a thermal design parameter in a higher degree than the other window types included in the study.

KEYWORDS: Window Design, Airflow, Computer Fluid Dynamics, Adaptive Envelopes, Thermal Sensation

1. INTRODUCTION

Windows are a significant part of building envelopes, both in terms of envelope area and envelope expression, and designed with primary focus to allow sunlight into indoor spaces. The ability to open a window, which is the case in most residential buildings and in many institutional buildings, enable furthermore air to travel from outside to inside and vice versa. Recent reports underline that indoor air is more polluting than outdoor air, due to human, inventory and equipment pollution (1,2). Controlling the airflow between indoor and outdoor, through the building envelope is thus an important performance parameter of the envelope design.

This study examines the air flow patterns and spatial phenomena created by the dynamic movement of window partitions, focused on nine specific window types. These types are chosen, as they represent the vast majority of window designs commercially available and thus have the most significant implementation in the designed built environment. The window types include the Single Hung, Double Hung, Awning Transom, Hopper Transom, Single Casement, Double Casement, Gilder, Vertical Pivot and Horizontal Pivot.

Previous studies of window design related to air flow phenomena are focused on single-sided ventilation conditions (3) and simple openings (4–6) for the understanding of flow conditions, air exchange rate and impact on thermal comfort.

This experimental simulation-based study explores a variation of different window types by identifying, catalogue, model, simulate and compare how the nine window designs and their movable partitions can generate, guide and define air flow phenomena as a basis for future environmental design in architecture and how they perform when they are extensively analyzed for their capacities to create environmental sensations.
The paper presents the experimental computational studies, the methods used, the behavioural performance of all the tested designs/positions and the air flow results for both utilitarian and sensorial capacities in future building envelopes.

Figure 1. Vertical Pivot window design, which both opens and steers the airflow.

35th PLEA Conference. Planning Post Carbon Cities.
DOI: https://doi.org/10.17979/spudc.9788497497947

2. METHODS

Airflow in and around buildings, and in complex urban conditions are affected by a complex mix of building geometries, spatial inventory, contextual elements and urban microclimates (7). However, to allow an isolated understanding of various window designs, and how they form air flow in relation to opening positions, Computer Fluid Dynamics (CFD) simulations are conducted in a series of systematic iterations through a parameterized design model, which is directly paired with a CFD analysis, and then compared for their relative performances across window types and opening degrees.

2.1 Simulation Studies

The nine window designs, including the sliding and rotation movements of partitions are modelled at one end of a space measuring 4x8x3 meters, fig.2, and coupled with a high resolution CFD simulation procedure, fig.3, where each window and ten partition positions are simulated with dynamic meshing to accommodate the changing geometric arrangement of window parts as they move. The coupled computational design and simulation model is based on the Rhino/ Grasshopper/Ladybug/Butterfly framework, utilising the OpenFoam kernel for CFD processing. Opposite of the window including moving elements, in the simulation space, is an outlet opening inserted, with the same dimensions as the inlet opening where the window is placed. This enables cross ventilation of the space based on the specific window and composition of movable parts. The external airflow, inducing the internal airflow, is maintained with an orthogonal direction to the building façade with 5 m/s velocity. A complete voxel-grid is analysed, and shown with 4 simulations planes, including one horizontal plane and three vertical cross-sectional planes, combined illustrating the resultant flow behaviour, fig. 3 and 13-20.

2.2 Comparative Analysis Studies

Each simulation run maps data that is then analysed for describing numerically the average air velocity, max/min velocities and auto-generate simulation meshes, which in reveal flow regions and spatial air flow zoning/boundaries, that cannot be identified by avg./max/min values. Values are then mapped and graphed, fig. 4-12, to compare the different window performances in generating, and controlling air flow velocities that can be utilized in environmental design strategies.

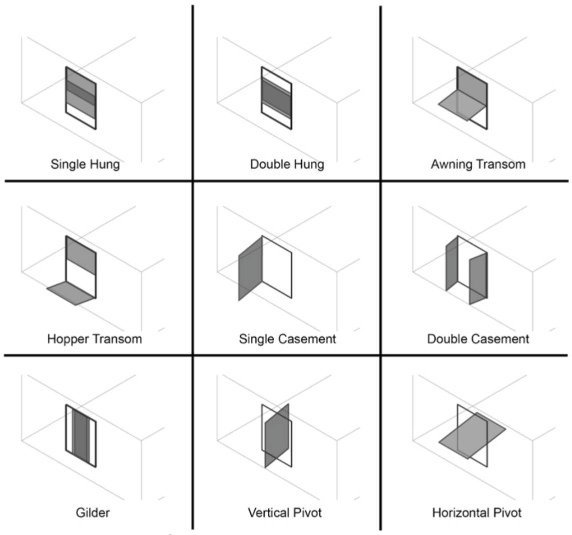

Figure 2. Matrix of window 9 designs, all with parametrically modelled movements to link window geometry composition to air flow simulation.

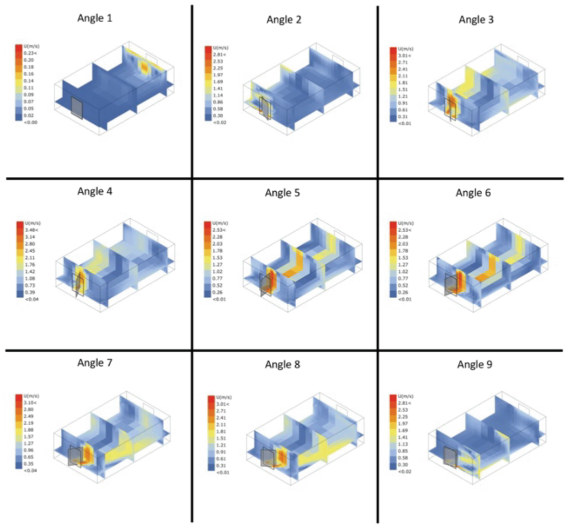

Figure 3. Computer Fluid Dynamics simulation of window 8 (vertical pivot) with 9 different opening positions, resulting in large variations in air flow velocity, directionality and zoning.

3. RESULTS

The results from the studies are presented in two series of figures, focusing firstly on the quantitative data of maximum, minimum and average velocities generated by each design across its opening degrees. The second series of figures look at the simulation planes, focused on the flow patterns that are generated by the specific window.

35th PLEA Conference. Planning Post Carbon Cities.
DOI: https://doi.org/10.17979/spudc.9788497497947

3.1 Flow Velocities

Each window is simulated for resultant internal velocities as a function of opening percentage related to the specific mechanism, sliding or rotational movement, of the window design. This means that a window, dependent of design, can be fully open, with a percentage of 50%. The reason for this somewhat counter logic condition, is that a double hung window slides its elements in a way where 50% movement is equal to 50% open, whereas a single casement window is 100% open after 50% rotational movement. This is clearly visible in figures showing the velocity patterns below.

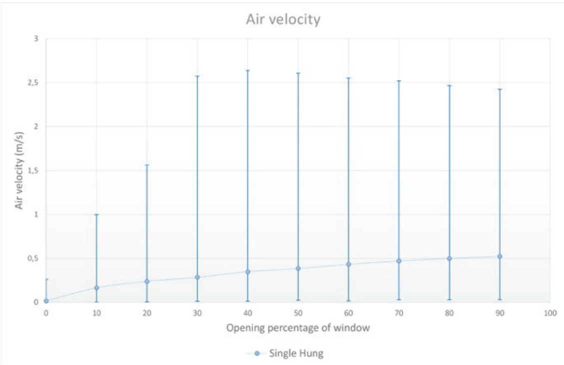

Figure 4. Air velocity values for a Single Hung design.

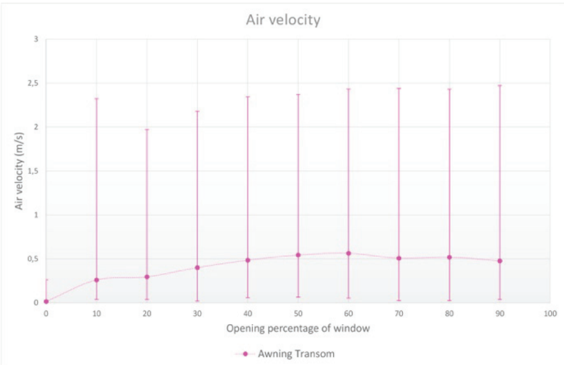

Figure 5. Air velocity values for an Awning Transom design.

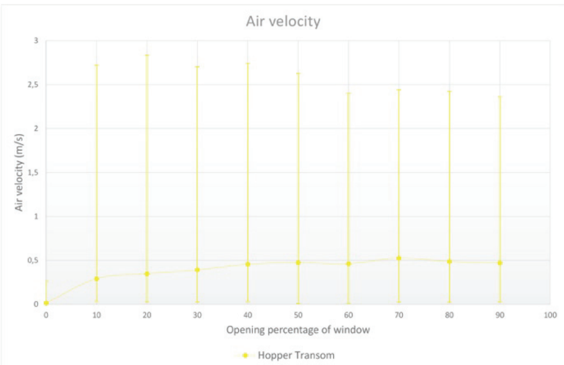

Figure 6. Air velocity values for a Hopper Transom design.

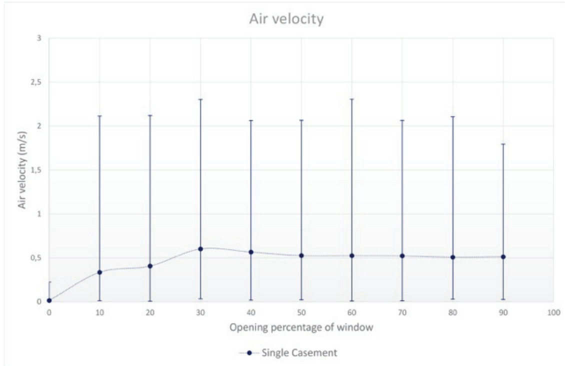

Figure 7. Air velocity values for a Single Casement design.

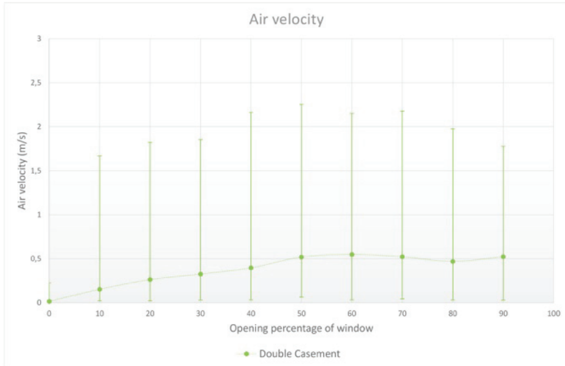

Figure 8. Air velocity values for a Double Casement design.

From the above 5 studies, it is the Hopper Transom design, which presents the highest velocities, and the most stable values across the openings, particularly when focusing on the average velocities of the internal space.

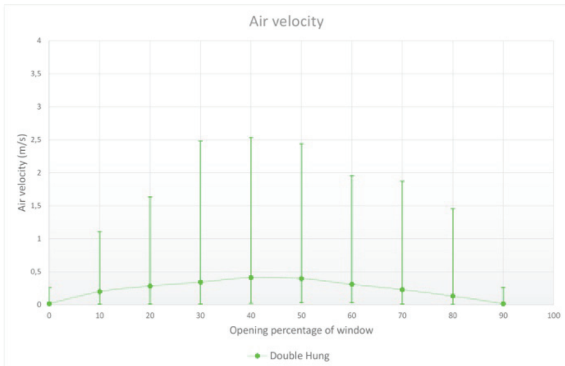

Figure 9. Air velocity values for a Double Hung design.

35th PLEA Conference. Planning Post Carbon Cities.
DOI: https://doi.org/10.17979/spudc.9788497497947

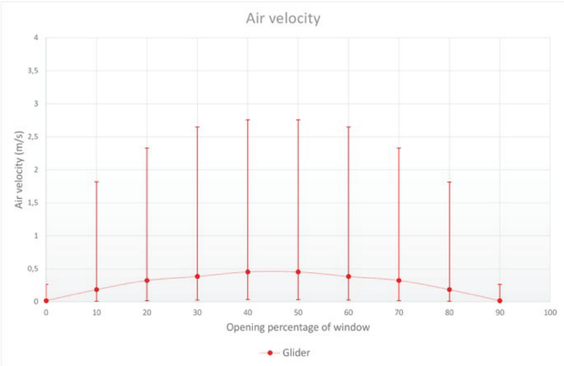

Figure 10. Air velocity values for a Glider design.

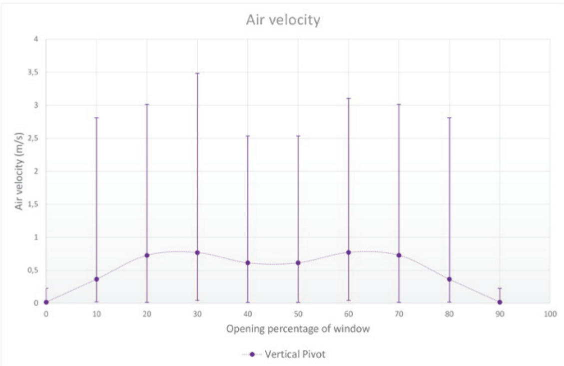

Figure 11. Air velocity values for a Vertical Pivot design.

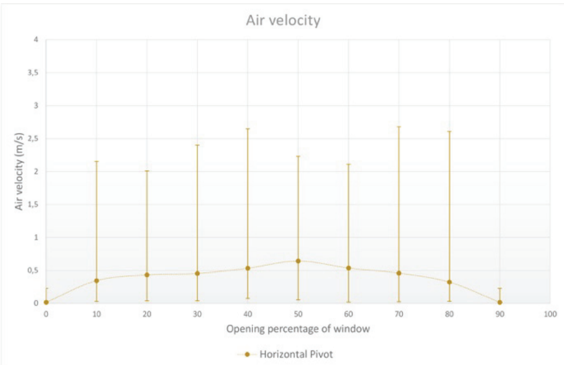

Figure 12. Air velocity values for a Horizontal Pivot design.

It is noticeable to see the relatively low velocity performance of the Double Hung window, with very low average values compared to the Hopper Transom mentioned above, where the Double Hung consistently lies below 0.5 m/s, with a larger part below 0.25 m/s, where the Hopper Transom maintains around 0.5 m/s across its openings above 20%. The same performance can be registered for the Glider design, with its horizontal movement, as opposed to the vertical movement of the Double Hung design.

In contrast are both the centre pivoting designs peaking above 3 m/s, with the Vertical Pivot showing a max of 3.5 m/s, well above the Hopper Transom peak at 2.8 m/s. The average values of the Vertical Pivot are equally the highest in this study, with 0.8 m/s from 20-30% open and again from 60-70% opening. This shows that the non-parallel window element, rotated approximately 20% of the wind direction, increases the flow velocity in the internal space, both in terms of max and averages values.

3.2 Flow Patterns

The flow regimes of the window and successive opening percentages are shown below, illustrating the ability for a window to steer air movement and velocities. The objective here is to understand the

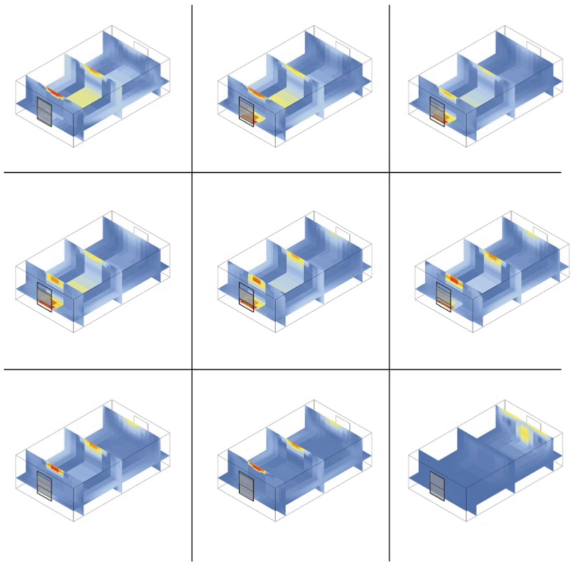

Figure 13. Double Sliding window design and flow patterns.

The vertical movement in plane with the building façade allows little ability to steer the airflow through element geometry guidance. Flow patterns are created by the simple opening, allowing air to flow in through the top, and bottom, creating a stream condition in the centre of the space directly towards the outlet placed in the opposing wall.

35th PLEA Conference. Planning Post Carbon Cities.
DOI: https://doi.org/10.17979/spudc.9788497497947

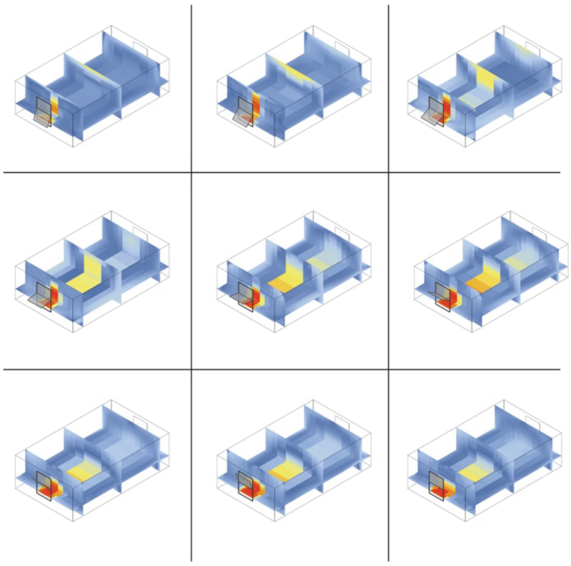

Figure 14. Hopper Transom window design and flow patterns.

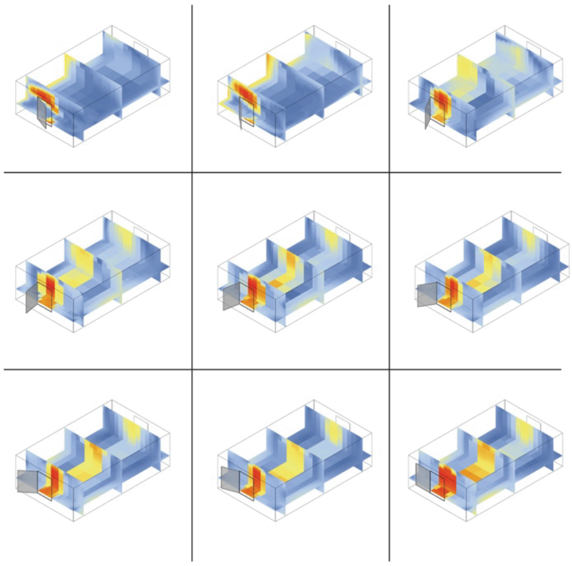

Figure 16. Single Casement window design and flow patterns.

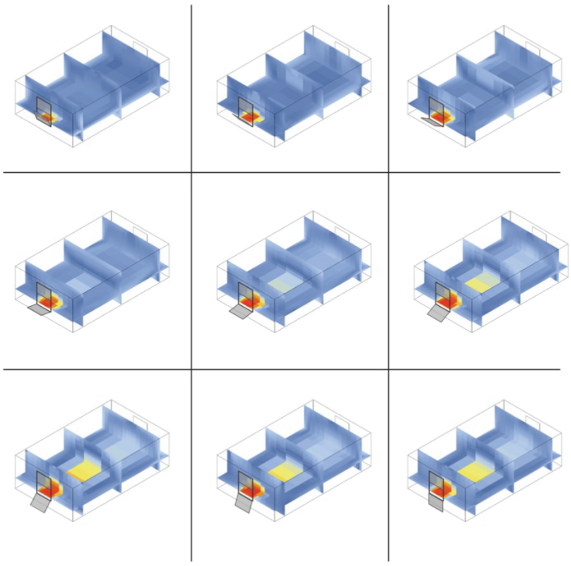

Figure 15. Awning Transom window design and flow patterns.

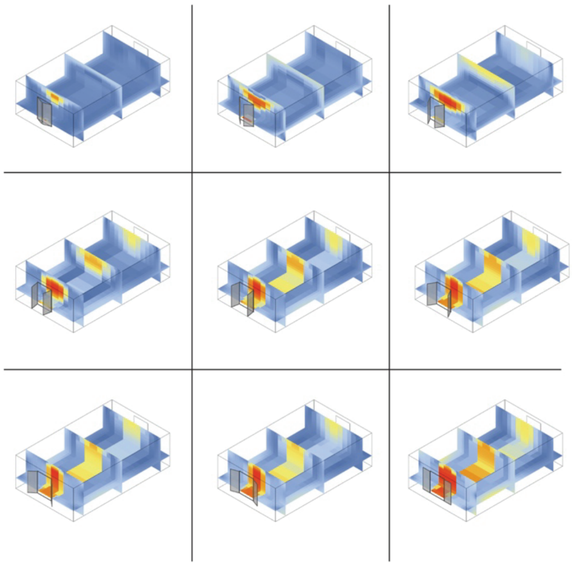

Figure 17. Double Casement window design and flow patterns.

The Hopper Transom, fig. 14, and Awning Transom, fig. 15, create airflows, which largely perform in similarity to the Double Sliding design, guiding the streamline directly to the opposing outlet wall. While rotating across the vertical axis, these patterns are also recognised in both the Single Casement, fig. 16, and Double Casement, fig. 17. The two differences should be noted, the airflow is stronger in both the casement designs, because the awning designs only utilise half the window area for opening, and, the Single Casement enables the steering of airflow, particularly at the lower opening degrees, in a higher manner than the Double Casement. The ability to steer the airflow in a higher degree enables an instrumentality for the occupant (and designer) to utilise this as part of creating thermal sensations within the space. This capacity is even more outspoken in both the centre vertical pivot designs, but with the Vertical Pivot window, fig. 19, allowing the highest degree of airflow control as a function of its opening percentage and thereby its plane orientation in relation to the outside airflow.

35th PLEA Conference. Planning Post Carbon Cities.
DOI: https://doi.org/10.17979/spudc.9788497497947

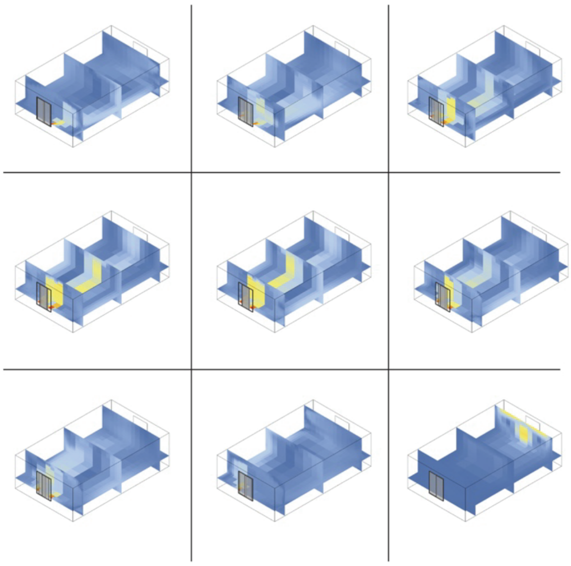

Figure 18. Gliding window design and flow patterns.

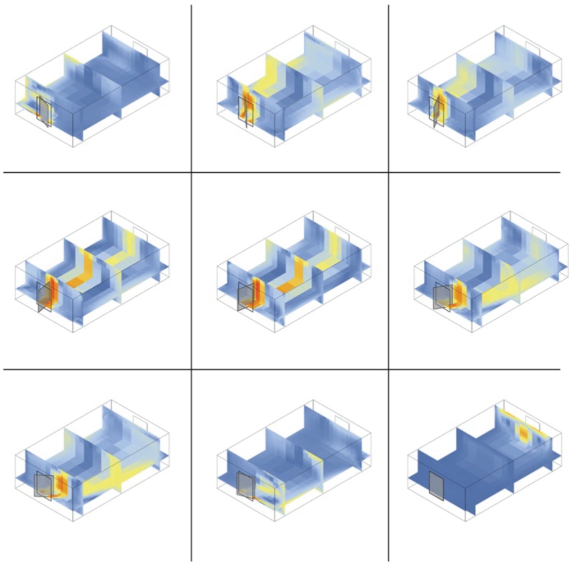

Figure 19. Vertical Pivot window design and flow patterns.

4. CONCLUSION

The study gives insights into how windows, when modelled with dynamic movable partitions, can generate, form and guide air flow patterns, which has a direct impact on thermal sensations and spatial definitions based on environmental forces. In this way, results can be used directly to design and programme building envelopes to create specific air flow-based phenomena, both in terms of utility (ventilation strategies) and sensory experiences (thermal tactile strategies). Three specific conclusions are here outlined:

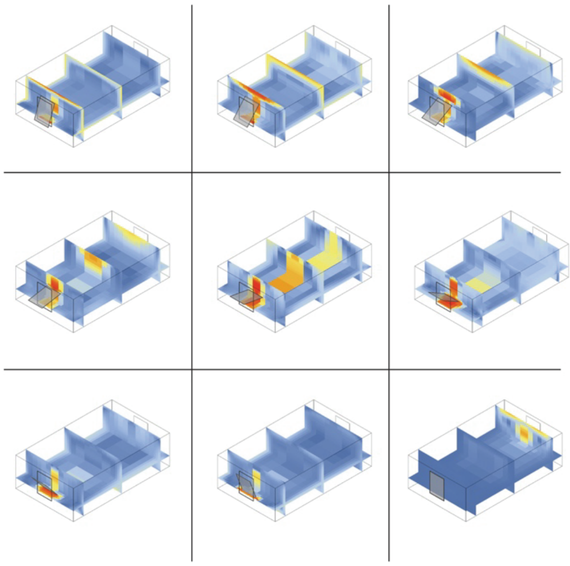

Figure 20. Horizontal Pivot window design and flow patterns.

1. Windows, across all types, have a high impact on internal air flow velocity, directivity and zoning.
2. Large variations of velocities are detected across windows types, with some windows enabling a five-fold local velocity condition, suggesting that both window design and its partition composition can be strategically used for passive and active environmental strategies in future envelopes.
3. The Vertical Pivot design has the highest performance for both max./avg. velocities and capacity to steer airflow.

REFERENCES

1. Hau IC. Fremtidens sunde indeklima. Danish Architecture Center; 2011.
2. Mikkelsen L, Jarby C, Dyck-Madsen S, Press-Kristensen K. Indeklima i Dagsinstitutioner. 2019.
3. Wang H. Modeling on single-sided wind-driven natural ventilation. 2015, Open Access Thesis Dissertations.
4. Prakash D, Ravikumar P. Analysis of thermal comfort and indoor air flow characteristics for a residential building room under generalized window opening position at the adjacent walls. Int J Sustain Environ . 2015;(February).
5. Masood OA, Guirguis NM, Al-hady MIA, Fahmi AA. Windows Factors Impact on Air Speed and Quality Inside Architectural Spaces. International Journal of Applied Engineering Research, 2018;13 (15)
6. Heiselberg P, Bjørn E, Nielsen P V. Impact of Open Windows on Room Air Flow and Thermal Comfort.. International Journal of Ventilation, 2016 1(2).
7. Oke TR. Boundary Layer Climates. Routledge; 1987.

DOI: https://doi.org/10.17979/spudc.9788497497947