FLUID MECHANICS OF SASH WINDOWS

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Natural Ventilation

In developed countries the energy consumption used to heat and cool buildings comprises up to 40% of the total energy use (Perez et al., 2008). Furthermore, effective ventilation can also limit the transmission of airborne infections such as COVID-19 by renewing the air in the room, leading to the need to improve our understanding of common ventilation strategies.

Counter-balanced vertically sliding windows, also called **sash windows** are used in many buildings and houses in northern Europe. Implementing natural ventilation strategies for sash window is an efficient way of reducing the building's energy consumption while improving the indoor air quality.

This work focuses on room-to-outside ventilation and considers the flow through a sash window when it is the only ventilation opening in the room. Indoors is well-mixed and the outdoor air is at rest.

Different flow regimes occur depending on the sash window opening configuration. A semi-analytic model is developed to predict the ventilation of the room for different sash window configurations and water tank experiments are performed to test and validate the model.

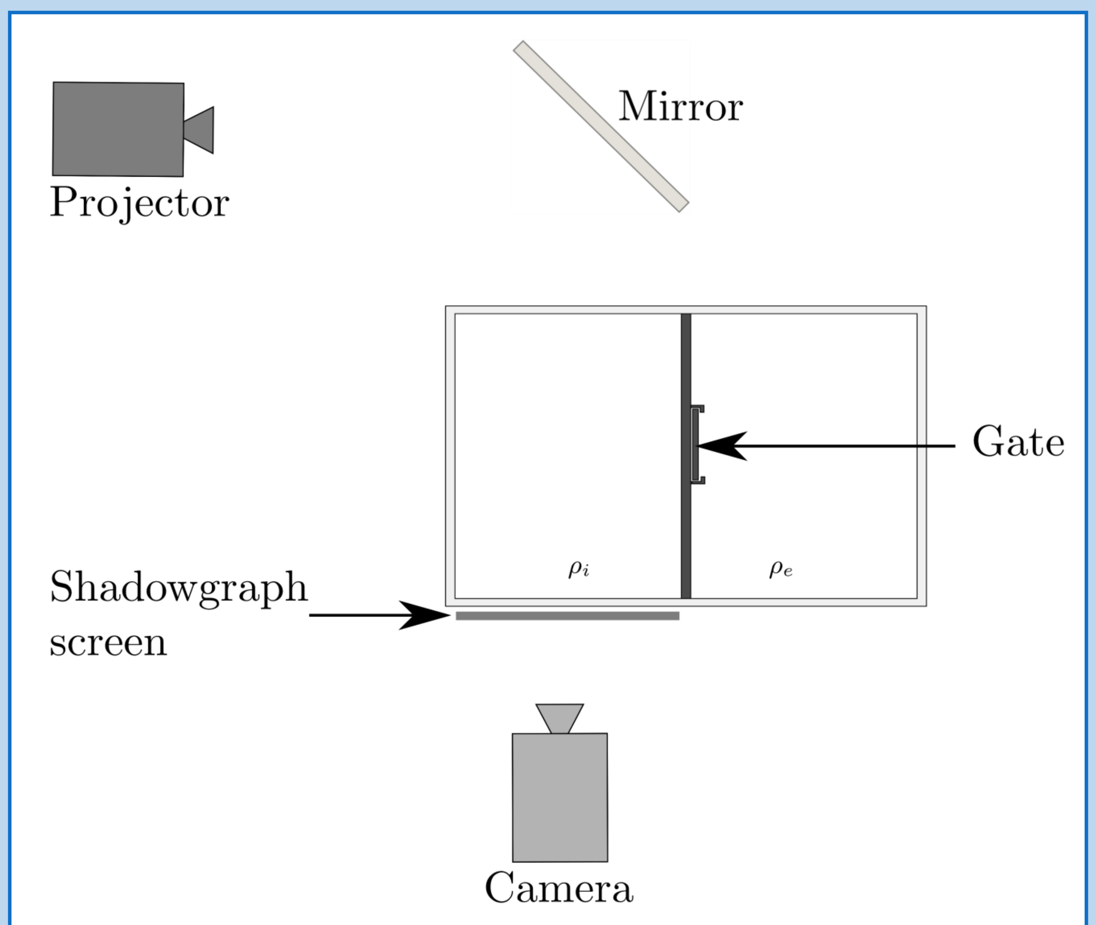

Fig 2. Schematic of the experiment with a top view of the tank divided into two compartments. The sash window opening is closed by the vertically-sliding gate.

Water tank Experiments

Small-scale experiments using fresh and salt water modelling respectively hot and cold air are performed to measure the flow rate for different sash window geometries.

The tank is divided into two compartments separated by an opening replicating a sash window and initially closed by a vertically-sliding gate. The two compartments are filled with fresh and salted water. At the start of the experiment the gate is removed, and water flows through the opening.

The flow rate through the sash window geometry can be calculated from the change in the water density on each side of the sash window.

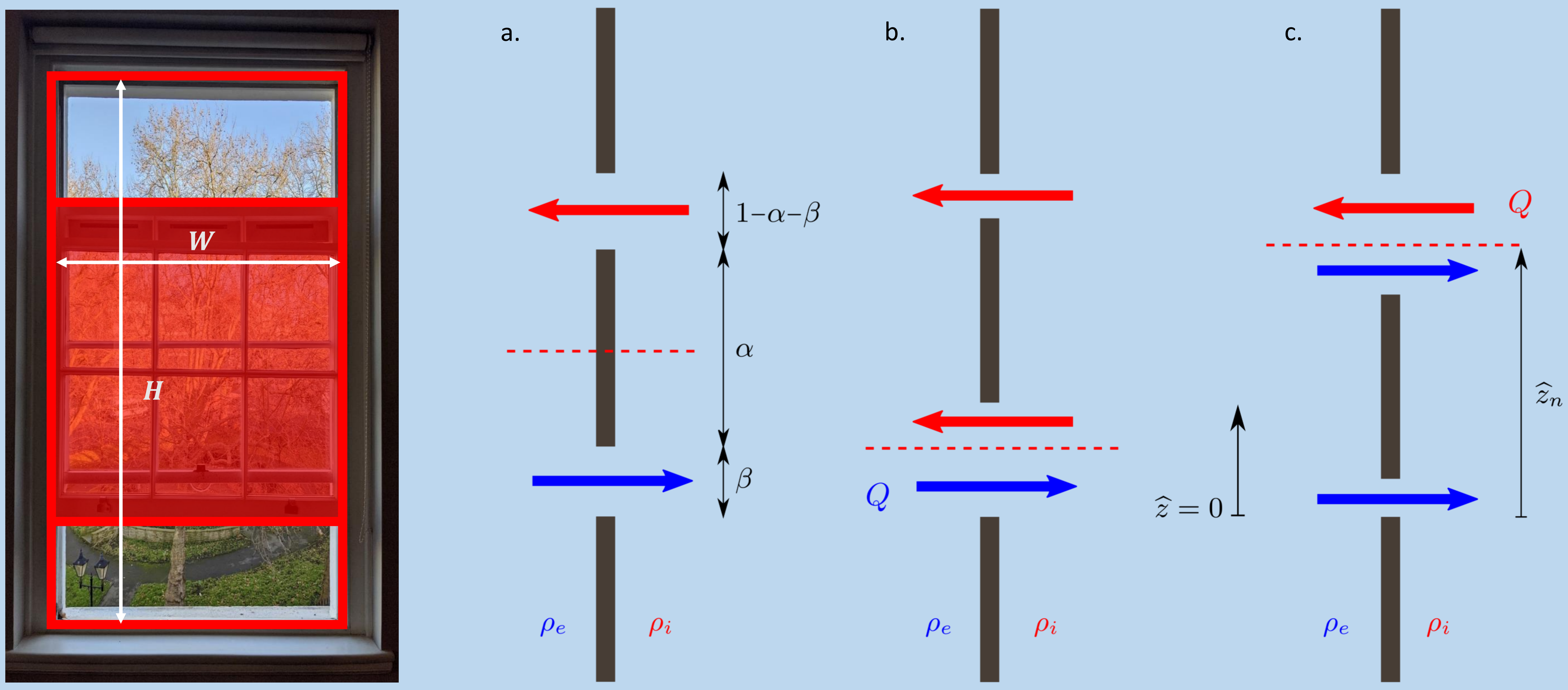

Fig 1. A traditional sash window has two sliding panes allowing the window to be open at the top and/or bottom. Depending on the geometry, the relative position of the neutral level will vary and different flow regimes appear: (a) unidirectional flow, (b) bidirectional flow at the lower opening and (c) bidirectional flow at the upper opening.

Flow regimes

The sash window geometry and the temperature difference determine a neutral level height, $\hat{z}_n$, where the pressure inside and outside is the same. Depending on its relative position one of three different flow regimes will occur: either a **unidirectional flow** with inflow through one opening and outflow through the other (Figure 1a), or a **bidirectional flow** through either the lower opening (Figure 1b) or the upper opening (Figure 1c).

The height of the lower opening for the transition from one regime to another is obtained analytically,

$$\beta_{crit} = \frac{2}{3} \times \frac{(1-\alpha)^{3/2}}{\alpha^{1/2} + (1-\alpha)^{1/2}}$$

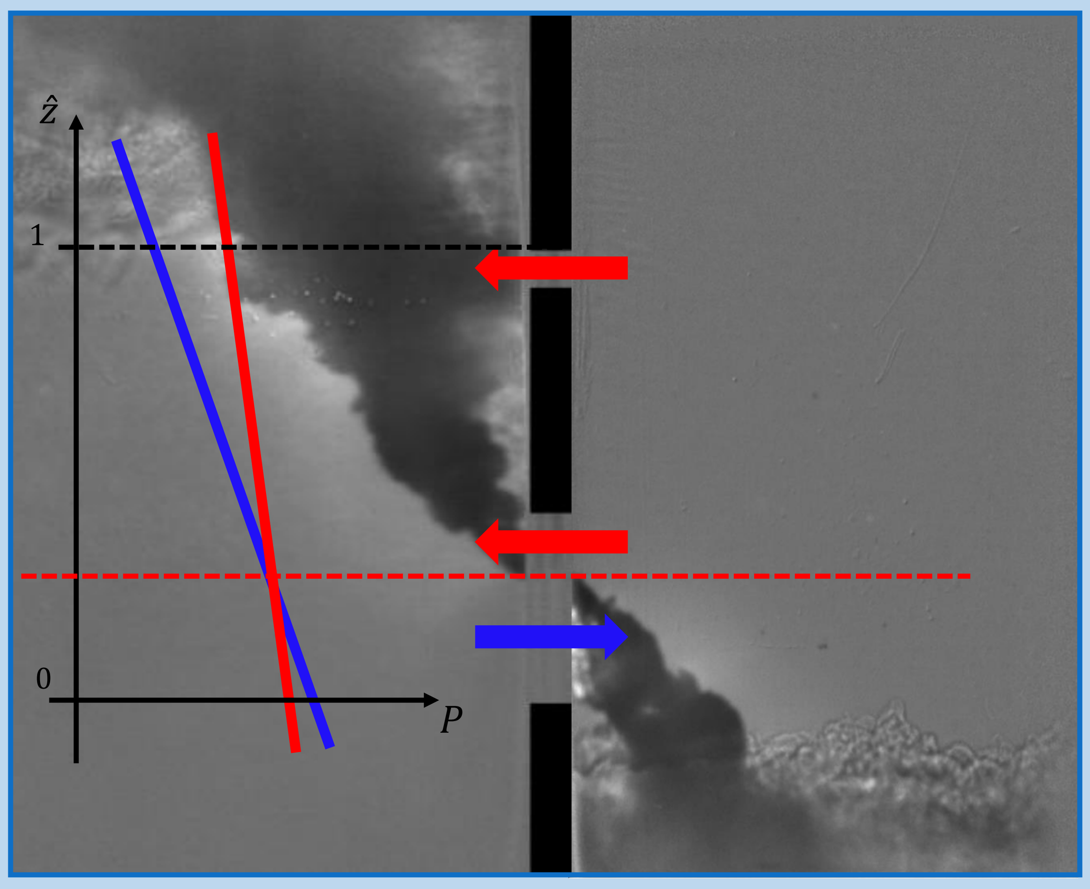

Fig 3. Shadowgraph of a water tank experiment for an asymmetric geometry. A bidirectional flow is observed in the lower opening, with light fluid flowing into the left tank and dense fluid flowing into the right tank. Pressure profiles are plotted as references.

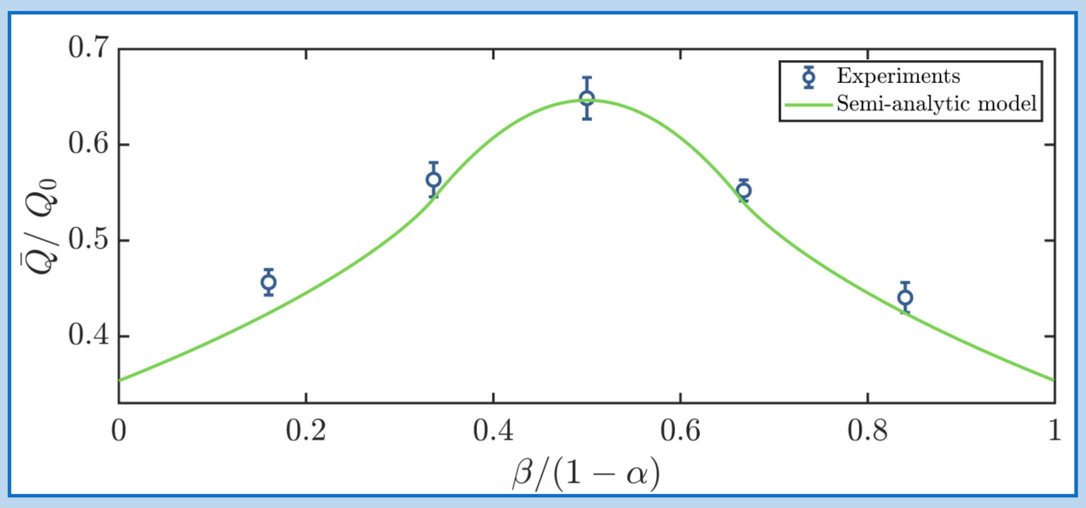

Fig 4. Variation of the flow rate measured experimentally and from the model.

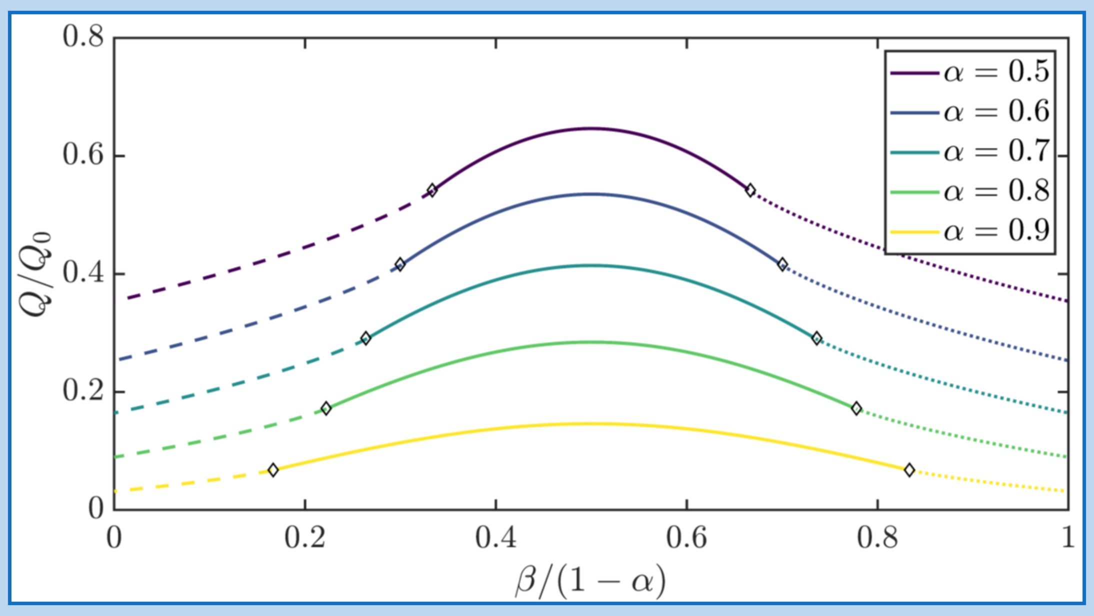

Fig 5. Variation of the flow rate, normalised by the flow rate of an open rectangular window of dimension $W \times H$, with the height of the lower opening. ◊ : transition from one regime to another.

Semi-analytic model

Assuming the pressure to be hydrostatic and applying Bernoulli's principle the flow velocity and the flow rate are determined, leading to the following volume conservation,

$$Q = \int_{\hat{z}_n}^{1} HWC_d v(\hat{z})\, d\hat{z} = \int_{0}^{\hat{z}_n} HWC_d v(\hat{z})\, d\hat{z}$$

where C_d is the discharge coefficient. By comparing the height of the lower opening with β_{crit}, the flow regime can be determined and the volume conservation equation solved for $\hat{z}_n$, enabling **calculation of the flow rates** (Fig. 5). A good agreement between the model's prediction and the experiments for the flow rate is shown (Fig. 4).

Conclusion

We have developed a model predicting the ventilation rates of a closed room with the flow driven by a temperature difference between indoors and outdoors through a sash window. Depending on the geometry of the window openings, **three flow regimes can be observed**. The small-scale experiments conducted in a water tank confirm the flow rates associated with the different geometries.

The model can be used to design ventilation system in **low energy buildings** or integrated into programs controlling the ventilation of **smart buildings**.

More details can be found in Kemp et al. (2022).

References :

Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. Energy and buildings, 40(3), 394-398.
Kemp, G. F., Wykes, M. S. D., Bhagat, R. K., & Linden, P. F. (2022). Fluid mechanics of sash windows. Flow, 2.

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