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Experimental study of a naturally ventilated system forced by wind fluctuations: preliminary results

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SUMMARY:
This experimental study investigates the effect of stochastic wind dynamics on naturally ventilated systems. In a previous theoretical study, we showed that wind fluctuations affect to a great extent the time-averaged dynamics of the room ventilation. This work reports initial outcomes of an experimental campaign performed in a wind tunnel, aimed to test the obtained theoretical results. Although preliminary, experimental results are in reasonable agreement with theoretical predictions, and confirm the key role of stochastic components in naturally ventilated systems.

Keywords: Natural ventilation, wind fluctuations, noise-induced phenomena

1. INTRODUCTION

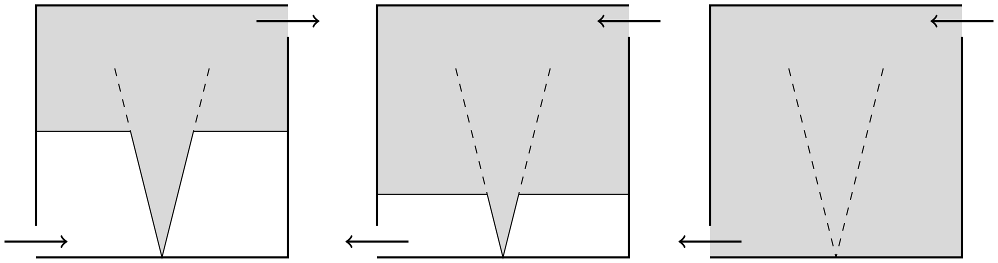
Over the last decades, natural ventilation has received a great deal of attention from the scientific community. Such an interest stems from the energy savings that can be obtained with this approach, and for the relevance in the issue of the air quality of enclosed spaces.

Several studies (Coomaraswamy and Caulfiled, 2011; Hunt and Linden, 2005) were conducted taking into account the presence of an external wind, which can considerably influence the dynamics of naturally ventilated systems. Almost all previous studies focused on deterministic wind-induced dynamics. Such a forcing is intrinsically complex, as it induces a bistability in the dynamics of the system. Nevertheless, due to atmospheric turbulence, in real cases wind exhibits a strong stochastic component; therefore, the necessity of considering wind fluctuations arises. In a previous work (Vesipa et al., 2023), we highlighted a structural change of the time-averaged behaviour of the system submitted to a stochastic wind forcing. This work aims at investigating experimentally the role of wind fluctuations, and compare the experimental results with the theoretical predictions.

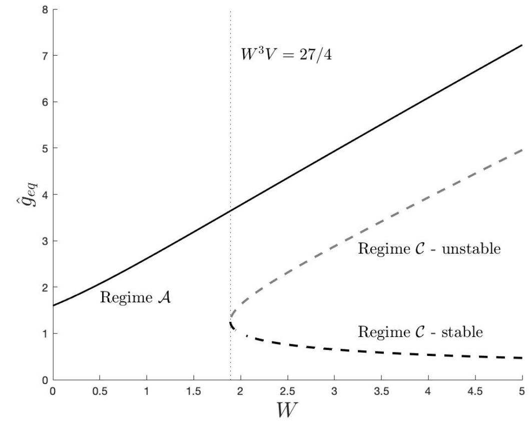
2. MATHEMATICAL MODEL

In order to model the natural ventilation dynamics occurring in a single room, the theory developed by Coomaraswamy and Caulfiled, 2011 is considered. The model considers a room of height H

that contains an isolated buoyancy point source at floor level, one ceiling-level opening and one floor-level opening. From the buoyancy source a plume of warm fluid rises, generating a two-layer stratification whose interface is located at height h above the floor. The warm air that accumulates at the ceiling of the room generates a stack effect that drives the room ventilation.
The dynamics can be altered when the wind contrasts the stack effect. More scenarios can occur depending on the strength of the wind. If the wind is weak enough, the stack effect is preserved and a forward flow is maintained (Regime $\mathscr{A}$, see Fig. 1a). Otherwise, if the wind is strong enough, it overcomes the stack effect and a reverse flow occurs. In this case two situations are possible: the two-layer stratification is preserved despite the reverse flow (Regime $\mathscr{B}$, see Fig. 1b), or the interior of the box is fully contaminated with plume fluid, i.e. $h = 0$ (Regime $\mathscr{C}$, see Fig. 1c). Regime $\mathscr{B}$ is a transient regime only: if wind persists for some time, Regime $\mathscr{C}$ is reached; otherwise (the wind strength reduces) the system returns in Regime $\mathscr{A}$.



(a) Regime $\mathscr{A}$ **(b)** Regime $\mathscr{B}$ **(c)** Regime $\mathscr{C}$



(d) Bifurcation diagram of $\hat{g}$ as function of W, for $V = 1$.

Figure 1. (a-c) Possible regimes in case of opposing wind. (d) Bifurcation diagram of $\hat{g}$ as function of W under deterministic conditions, when $V = 1$.

The dynamics of the system can be described as a function of two dimensionless parameters - the venting parameter V and the wind parameter W (Coomaraswamy and Caulfiled, 2011) - by the following equations

$$-\frac{\mathrm{d}\hat{h}}{\mathrm{d}\hat{t}} = \begin{cases} \hat{h}^{5/3} - |V\hat{g}(1-\hat{h}) - VW|^{1/2} \\ \hat{h}^{5/3} + |V\hat{g}(1-\hat{h}) - VW|^{1/2} \\ 0 \end{cases} , \frac{\mathrm{d}}{\mathrm{d}\hat{t}}[\hat{g}(1-\hat{h})] = \begin{cases} 1 - |V\hat{g}(1-\hat{h}) - VW|^{1/2}\hat{g} & (\mathscr{A}) \\ 1 & (\mathscr{B}) \\ 1 - |V\hat{g}(1-\hat{h}) - VW|^{1/2}\hat{g} & (\mathscr{C}) \end{cases} , \quad (1)$$

where $\hat{h} = h/H$, and $\hat{g}$ is the reduced gravity in the buoyant warm layer scaled with the reduced gravity of the buoyant plume when it reaches the top of the box. The letters ($\mathscr{A}$-$\mathscr{C}$) refer to the corresponding modelled regimes for both the equations.

Under deterministic conditions, when the wind parameter W keeps constant over time, steady solutions of the system (1) exist (see Fig. 1d, where steady states of $\hat{g}$ as function of W are shown). In particular, a steady stable solution in Regime $\mathscr{A}$ exists for any value of V and W. Concerning Regime $\mathscr{C}$, solutions exist if and only if $W^3V > 27/4$; in this case two steady solutions occur, one stable and one unstable.

When wind undergoes stochastic oscillation of velocity, a noise-induced transition can be observed (Vesipa et al., 2023). When the system is sufficiently close to the bifurcation condition, the stochastic forcing causes a structural change of the time-averaged behaviour of the system. Namely, the interface between the warm and cold layers fluctuates around a time-average value which is significantly lower than the interface elevation observed when wind is constant. In addition, the reduced gravity in the buoyant layer in the case of fluctuating wind is lower than the reduced gravity in the case of constant wind. The dependence of such a difference on wind characteristics and on relative strength of wind over thermal loads was shown in a previous work (Vesipa et al., 2023).

3. EXPERIMENTAL SETUP AND RESULTS

Experiments were conducted at the Laboratoire de Mécanique des Fluides et d'Acoustique (LMFA) at the École Centrale de Lyon, France. Experiments were performed by using a transparent box 29.5 cm long, 15 cm wide and 25 cm high. Dimensions refer to the inner of the box. Four circular holes (diameter 2 cm) were cut on the vertical faces (two at the leeward face at ceil level, two at the windward face at the floor level). For this geometry, the vent parameter was $V = 0.026$. The effect of the wind was simulated in a closed-circuit wind tunnel (see Fig. 2). The test section of this tunnel was 8 m long, 1 m high and 0.7 m wide. The mean speed of flow of the wind tunnel was varied to change the wind parameter W. Wind fluctuations were obtained installing a bluff body upwind the box. In a first experimental phase, the flow field was charactetrized. The mean velocity $\underline{u}$ and the coefficient of variation of the wind velocity $\sigma_u/\underline{u}$ were measured placing the bluff body at different locations. Different locations led to different values of $\sigma_u/\underline{u}$.

The buoyancy source was reproduced by the injection of carbon dioxide through a circular nozzle (diameter 0.9 cm) positioned in the centre of the top box. In this experimental set-up, the bottom of the box represents the ceiling of the room while the top face is the floor.

The carbon dioxide flux carried also a small ammount of nebulized oil. This was necessary to detect the buoyancy layer interface (by using a laser plane). Experiments were filmed, and video processing allowed the the elevation of the interface between the two layers to be continuously measured. The reduced gravity in the buoyancy layer was also estimated from measures taken by a carbon dioxide sensor.

In Figure 3 the experimental results (markers) and the expected behaviour from theory (lines) are reported. Theoretical results refer to the case of constant wind only. In case of constant wind (black circle), the results are in agreement with the theoretical prediction and fit the theoretical curve very well. When wind fluctuations occur (coloured triangles) the reduced gravity is much

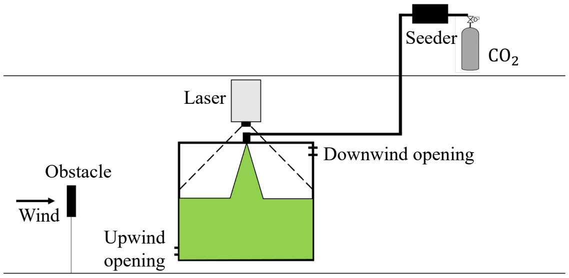


Figure 2. Lateral view (w.r.t. wind direction) of the experimental setup. Green shaded area refers to the carbon dioxide seeded with oil, which is visualised using a green laser plane.

lower than the reduced gravity obtained in case of constant wind, as expected by (Vesipa et al., 2023). It should also be noted that for low values of W the effect of wind fluctuations is less severe (black and coloured markers are comparable). When W approaches the bifurcation point, all the colored markers ($\sigma_u/\underline{u} > 0$) are below the black markers. The transition to Regime $\mathscr{C}$ occurs for lower values of W when $\sigma_u/\underline{u} > 0$. This can be deduced because the lowest value of W at which transition to Regime $\mathscr{C}$ takes place is associated with the highest value of $\sigma_u/\underline{u}$ (blue markers).

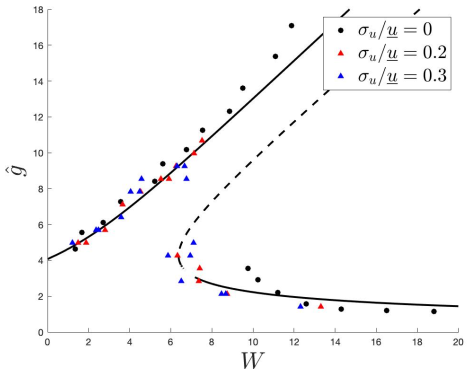


Figure 3. Experimental results (markers) and theoretical behaviour in case of constant wind (black lines).

4. CONCLUSIONS

The results obtained from this set of experiments are in agreement with the outcomes of the theoretical study by(Vesipa et al., 2023). The alteration of the time-averaged dynamics of ventilated systems is observed when a stochastic forcing occurs. Furthermore, transition to fully mixed regime takes place for lower values of the wind parameter W. It is planned to run additional experiments (accounting for a wider range of $\sigma_u/\underline{u}$) to obtain more robust statistics on the collected data.

REFERENCES

Coomaraswamy, I. A. and Caulfiled, C. P., 2011. Time-dependent ventilation flows driven by opposing wind and buoyancy. Journal of Fluid Mechanics 672, 33–59.

Hunt, G. R. and Linden, P. F., 2005. Displacement and mixing ventilation driven by opposing wind and buoyancy. Journal of Fluid Mechanics 527, 27–55.

Vesipa, R., Ridolfi, L., and Salizzoni, P., 2023. Wind fluctuations affect the mean behaviour of naturally ventilated systems. Building and Environment 229, 109928.