RB-003

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RB-003: Velocity Decay and Near-Field vs. Far-Field Capture

P0 — Foundation

EXECUTIVE SUMMARY

This paper extends the plume characterization of RB-001 and the entrainment analysis of RB-002 by performing a comprehensive velocity decay and capture analysis for outdoor barbecue ventilation. It models continuous velocity profiles from 6 inches to 72 inches above the cooking surface, derives off-centerline Gaussian velocity profiles, defines the momentum-based capture criterion for outdoor buoyant plumes, calculates minimum CFM requirements at each standard mounting height for all source types, and identifies maximum practical mounting heights. The CFM-versus-height tables and critical mounting height analysis are the key engineering deliverables that RB-008 will build on.

THE CHALLENGE

The practical engineering problem is this: an outdoor hood designer must specify two parameters — the hood's physical dimensions (addressed in RB-002) and its exhaust flow rate in CFM (addressed here). The CFM must be sufficient to:

Outdoor Ventilation Standard

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Key Quantitative Findings

Still-air adequacy (v_edge > 0.15 m/s): Satisfied for all gas grill configurations at all heights, and for most other sources at heights of 24 inches and above. At 18 inches, charcoal and pellet low are marginally below the threshold, meaning that even slight ambient air movement could cause edge spillage. However, at 18 inches the plume is narrow and the hood overhang is generous, so the practical risk is low.

Light wind resistance (3 mph / 1.3 m/s, component approximately 0.9 m/s): Not achieved by any configuration at the K_CFM = 3.0 exhaust rate. This confirms that the K_CFM = 3.0 multiplier provides adequate still-air and light-variable-breeze protection, but does not provide full edge velocity resistance against sustained directional wind. Sustained wind protection requires the K_CFM = 3.68 multiplier (Table 3.8b) combined with the hood overhang margins from RB-002, which together provide geometric and volumetric wind protection.

Still-air capture reliability > 95%: At least 95% of the plume buoyancy flux (and corresponding contaminant flux) is captured under still-air conditions. This requires the hood to extend to at least the 98% time-averaged flux contour with margin for turbulent intermittency.

Light-wind capture reliability > 80%: At least 80% of the plume contaminant flux is captured when a 3 mph (1.3 m/s) crosswind deflects the plume. This requires the hood to extend beyond the deflected plume boundary on the downwind side.

Moderate-wind capture reliability > 60%: At least 60% of the plume contaminant flux is captured in a 7 mph (3.1 m/s) crosswind. Below this threshold, the hood is considered ineffective and the installation requires wind shielding.

CFM requirement increases by a factor of 4.0. The hood must exhaust 4 times more air to capture the same plume. This drives blower size from a moderate 300 CFM unit to a large, noisy 1200+ CFM unit.

Hood width increases by 41%. The hood grows from 49 inches to 69 inches — a substantial increase in material, weight, structural support, and visual impact.

Wind vulnerability triples. The plume deflection in a 3 mph wind increases from 4 inches to 12 inches. At 48 inches, even a light breeze pushes the plume nearly a foot off-center, potentially moving the plume edge beyond the hood boundary.

Centerline velocity decreases by only 26%. This is the one parameter that changes modestly — but it is not the binding constraint. The plume velocity is adequate at all heights. The binding constraints are mass flow (which increases rapidly) and geometry (which expands).

Temperature excess drops by 80%. The plume at 48 inches is barely warm (23 K above ambient), making it thermally indistinguishable from ambient air over much of its cross-section. This thermal weakness makes the plume difficult to contain because its buoyancy-driven coherence diminishes.

Why This Research Matters

This research provides the first physics-based, quantitative methodology for outdoor cooking ventilation design. These findings enable proper hood sizing, CFM specification, and mounting height selection — preventing the common failures that occur when indoor assumptions are applied outdoors.

📄 The Full Research Paper Includes:

✓ Complete derivations and governing equations
✓ Quantitative design tables and correction factors
✓ Engineering methodology with worked examples
✓ Interactive calculation tools and diagrams
✓ Full reference bibliography and validation data