IN-DEPTH SURVEY REPORT:

EVALUATION OF AND RECOMMENDATIONS FOR CONTROL TECHNOLOGY IN GRAY- IRON FOUNDRY SHAKE-OUT

at

Eljer Plumbingware, Shake-out Number Three
Salem, Ohio

REPORT WRITTEN BY
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SIC CODE:	3321
SURVEY DATE:	December, 1998
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DISCLAIMER

INTRODUCTION

Eljer Plumbingware, Inc in Salem, Ohio is a gray iron foundry, which has a history of overexposures to silica and carbon monoxide The most difficult operation from an exposure control point of view is the shake-out of bath tub castings, which occurs at shake-out number three Since the 1970s, this operation has either been out of compliance or the workers have been in respirators, despite the cardiovascular demands of the job This situation has continued despite the costly installation of the current ventilation system Due to these past difficulties, a new design approach has been employed the supplementation of classical ventilation design techniques with a type of numerical modeling called computational fluid dynamics (CFD) With the modeling of various ventilation design options for shake-out number three, ideas can be tested quickly and economically After more than fifty simulations using CFD and many conversations with representatives of the ventilation consulting company that was hired to design and install a new system, a ventilation expert and former NIOSH employee, and the Eljer plant engineer, promising results have emerged A systematic process of combining elements of the existing system, the consulting firm's proposed design, and innovations from brainstorming sessions resulted in some informed design options

BACKGROUND

Process Information

The process at shake-out number three begins when the shake-out operators roll the flask to the end of the pouring line The shake-out crane then moves the flask to the shake-out Next, the flask crane moves the cope to half of the shake-out, while the drag containing the casting remains on the other half of the shake-out Both the cope and drag are shaken out The cope is picked up by the flask crane and moved to the beginning of the pouring line Meanwhile, the shake-out operators use tongs to pull gates and risers from the bathtub casting, and place a hook through the tub drain opening The shake-out crane lifts the tub casting and moves it to the transfer line, where it is cooled as it travels to casting cleaning, while the flask crane moves the drag to the beginning of the pouring line

Exposure Concerns

Silica and carbon monoxide

Existing Controls

The existing ventilation at shake-out number three (shown in Figures 1 and 2) has elements of canopy and push-pull configurations Supply air is delivered on each side of the process, at a height that also provides cooling for the workers The exhaust hoods on each side form a partial canopy above, making use of the buoyant natural convection of this hot process, although the hoods are too far from the contaminant source to be classified as receiving hoods[1] The area above the process must remain open to allow the shake-out and flask cranes, which move the work pieces, to travel The existing process would require substantial modification before a true canopy would be possible

METHODOLOGY

Exposure Evaluation

Personal, full-shift monitoring was performed to assess crystalline silica exposures among the workers at shake-out number three over a two day period Four workers were monitored each day Six workers were present on the first day and four on the second day

Control Evaluation

Because of the substantial cost of a new ventilation system and a previous ventilation overhaul that failed to reduce exposures sufficiently, the latest proposed design (the third attempt to control exposure at shake-out number three) was simulated using computational fluid dynamics (CFD) to gain qualitative performance insights Performance information is more cost-effective before fabrication and installation Two-dimensional CFD models were created for both the existing system and the proposed system using identical techniques CFD is a numerical technique, which solves the system of equations that describe fluid behavior Applied here, the fluids are air and a contaminant that needs to be controlled The contaminant source was a model of the casting—a box cross section (because we are working in 2D) of height 3 5 ft and width of 6 ft The source temperature was set at 1200 F because the iron was rose-colored during shake-out In the model contaminant with the physical properties of air was emitted at a fairly high indoor air velocity (0 3 m/s) from the top and sides[2] Fluid properties were allowed to vary with temperature according to kinetic theory Turbulence was modeled using the k-ε RNG scheme With turbulence intensity and length scale used as boundary conditions, intensity was set at 10 per cent and length scale at 7 per cent of the dimension of the hood face or source surface Inside cells, variables were interpolated using the power law, except in one case that involved only natural convection, where the power law solution was unstable There, first-order upwind interpolation was used instead Because of the increased number of equations being solved in the application of kinetic theory to the fluid properties and because of small values of variables, the double precision solver was employed to minimize truncation error

RESULTS OF EVALUATION

Exposure Evaluation

Personal exposure monitoring of the shake-out operators was performed to obtain a reference point, against which the performance of the modified or replacement ventilation system could be measured The tabulated results follow

Personal Exposure Monitoring Shake-out Number Three

DATE	JOB TITLE	TWA RESPIRABLE DUST (mg/m^3)	PEL (mg/m^3)	8-HOUR TWA RESPIRABLE QUARTZ SILICA (mg/m^3)
12/3/98	Shake-out Operator	0 773	0 2301	0 3150
	Shake-out Operator	1 54	0 3578	0 3801
	Shake-out Relief	0 835	0 2759	0 2770
	Shake-out Operator	0 507	0 3279	0 1397
12/4/98	Shake-out Operator	0 292		ND
	Shake-out Operator	0 585	0 2762	0 1593
	Shake-out Operator	0 590	0 2138	0 2304
	Shake-out Operator	0 546		ND

Summary

JOB TITLE	TWA RESPIRABLE DUST (mg/m^3) N=8	TWA RESPIRABLE QUARTZ SILICA (mg/m^3) N=6	PEL (mg/m^3) N=6	8-HOUR TWA RESPIRABLE QUARTZ SILICA (mg/m^3) N=6
Shake-out Operator or Relief	GM=0 639 GSD=1 61	GM=0 256 GSD=1 43	GM=0 276 GSD=1 22	GM=0 235 GSD=1 48

Because the results for quartz silica lost due to lack of sample were probably low, bias would be introduced if the mean was formed only from the samples with measurable levels Instead, for the purpose of comparing contaminant control between the two days, total respirable dust was used, since all of those results were in the detectable range The geometric mean for the first day of sampling, 0 842, was greater than the geometric mean for the second day, 0 485 The first day of sampling occurred under conditions as they were observed These conditions included main cooling fans operating and the overhead exhaust not operating On the second day, the fans were kept off and the overhead exhaust was running The difference in the results for the two days was probably due mostly to these factors Nevertheless, the two days of sampling, together, represent the performance of the existing control measures, and as such are represented by a single geometric mean (GM) and geometric standard deviation (GSD) in the summary table The product of the GM and GSD for 8-hour TWA respirable quartz silica is greater than the product of the GM and GSD for the PEL, indicating that the PEL is likely to be exceeded

Control Evaluation

Man-cooling fans were being used, and the exhaust hoods were not functioning on the first day of the survey Not surprisingly, observation of the aerosol generated by the process and smoke visualization revealed inadequate ventilation performance These observations were recorded on video On the second day of the survey, the man-cooling fans were shut off and the exhaust hoods were turned on Qualitatively different flow patterns were observed and recorded A large portion of visualization smoke generated at the position of the work pieces was observed to be captured by the exhaust hoods

Computational Fluid Dynamics Simulation

Seventeen ventilation scenarios are reported here The strategy was to simulate the existing system, the proposed system, and modifications to each including a hybridization of the

two

Shake-out Number Three Simulation Outcomes

Description	Overhead Hood Flow (m/s)	Floor Slot Flow (m/s)	Side Hood Flow (m/s)	Average Concentration ($C/C_{natural}$)	CQ/G
Existing system off, natural convection from hot process	0 00	0 00	0 00	1 00	0 00
Hybrid existing system with proposed floor slot used as exhaust, matching supply velocity	-4 8	-3 00	3 00	0 304	0 0714
Proposed system, dual exhaust	-10 5	-1 016	0 00	0 221	0 0335
Hybrid of existing supply and proposed exhaust	-10 5	0 00	7 68	0 219	0 0609
Proposed system, exhaust only	-10 5	0 00	0 00	0 158	0 0217
Proposed system as originally designed	-10 5	1 016	0 00	0 115	0 0174
Existing system as observed	-4 80	0 00	7 68	0 107	0 0299
Hybrid existing system with proposed floor slot widened to casting, used as	0	-5 0	7 68	0 100	0 0302

exhaust					
Hybrid existing system with floor slot at casting used as exhaust	-4 8	-5 0	7 68	0 0912	0 0339
Existing system with doubled ventilation rates	-9 60	0 00	15 36	0 0885	0 0598
Hybrid existing system and proposed floor supply	-4 8	1 016	7 68	0 0650	0 0190
Hybrid existing system and proposed floor supply at 60 degree angle	-4 8	1 016	7 68	0 0614	0 0180
Hybrid of existing supply and proposed exhaust, plus floor exhaust at casting, existing exhaust duct left in	-10 5	-5 0	7 68	0 0273	0 0101
Hybrid of existing and proposed	-4 8 and –10 5	1 016 at 60 degree angle	7 68	0 0193	0 00827
Hybrid existing system with floor slot at casting used as exhaust (existing exhaust sealed)	0 00	-3 0	7 68	0 0141	0 00277
Hybrid existing system with proposed floor slot widened to casting, used as	0 00	-3 0	7 68	0 0119	0 00212

exhaust (existing exhaust sealed)					
Hybrid of existing supply and proposed exhaust, plus floor exhaust at casting, existing exhaust ducts removed	-10.5	-5.0	7.68	0.00903	0.00335
Hybrid existing system with floor slot at casting used as exhaust (existing exhaust sealed)	0.00	-5.0	7.68	0.00769	0.00180

The table is arranged so that the scenarios are ranked by exposure. Exposure is defined here as the average tracer gas mole fraction (C) at a height of 1.5 meters, and within two meters, horizontally, of the workpiece[3]. The choice of two meters was based on observation of the position and movement of the workers. The results for the ventilation scenarios are normalized by the concentration found without ventilation ($C_{natural}$). Thus, the dimensionless exposure is ($C/C_{natural}$). The highest exposure is predicted for the case of no mechanical ventilation. Of course this is expected, but its inclusion provides a fundamental basis against which other scenarios can be evaluated. An important test of a numerical simulation is whether the solution seems physically realistic. Far higher exposures under the non-ventilating condition are in line with physical intuition. Another quantity includes both exposure and energy-use information, CQ/G, the rightmost column in the table. The contaminant generation rate, G, was constant in this simulation The product of concentration and flowrate, CQ, can then be interpreted as how efficiently the exposure was reduced, in other words how much air had to be moved Figures 3 through 6 show the schematic geometry of the flow boundaries (*i e* ducts, floor, and casting) and the velocity vectors of the flow for no mechanical ventilation, the existing system, the consultant's design, and a hybrid favored by the CFD results, respectively The velocity magnitude is indicated by both the length of the vector and the color, with the red end of the spectrum indicating higher speeds

DISCUSSION

In the simulations the system designed by the consultant performed with approximately the same efficacy as the existing system, in terms of concentration of tracer gas at breathing zone height Certain hybrids of the two systems performed better These designs employed the existing side supply and either floor supply or floor exhaust Less clear is the effect of overhead exhaust, either of the existing system or the proposed system The simulation results should be used only as a guide to inform the design process, not as a quantified prediction of performance of the actual ventilation system. With that in mind, a reasonable approach would be to look at the designs with the lowest exposure results, and form a design from these and ventilation design experience The five scenarios at the bottom of the table stand-out clearly as being lower in exposure than the rest These all make use of the existing side supply The four lowest involve floor exhaust at or near the casting Simply adding the proposed system (with the floor supply modified to a 60 degree angle with the floor, toward the casting) to the existing system was the fifth lowest predicted exposure, but the energy cost was large, with the second highest volumetric flow rate of the fifteen designs presented

CONCLUSION AND RECOMMENDATIONS

Using CFD, a large number of designs were evaluated While numerical evaluation is less accurate than full-scale experimental testing, the latter method is prohibitively expensive for multiple designs The design proposed by the ventilation consultant was formulated using expertly-applied, traditional ventilation design techniques It is recommended that the results of the CFD analysis be used to identify qualitative factors that point the way to an optimal design, and that historical ventilation design experience be used to bring the design to its final form The CFD analysis indicated the following

- The existing side supply is effective at limiting horizontal spread of the contaminant plume and providing clean air to the work area
- Floor exhaust near the shake-out table is effective at capturing contaminant
- The existing exhaust *ducts* act as a kind of ceiling in the work area and thus provide some direction to the supply jet, aiding its effectiveness
- Overhead exhaust did not have a clear effect

REFERENCES

1 National Institute for Occupational Safety and Health, An Evaluation of Occupational Health Hazard Control Technology for the Foundry Industry 1978 Superintendent of Documents, U S Government Printing Office, Washington, D C , Pub No DHEW (NIOSH) 79-114, pp 77-78

2 Baldwin, P E J and Maynard, A D A Survey of Wind Speeds in Indoor Workplaces *Ann Occup Hyg* Vol 42 No 5 pp 303-313

3 Bennett, J S , Feigley, C E , Khan, J , Hosni, M H Comparison of Mathematical Models for Exposure Assessment With Computational Fluid Dynamic Simulation *Applied Occupational and Environmental Hygiene* 15(1) 131-144, 2000

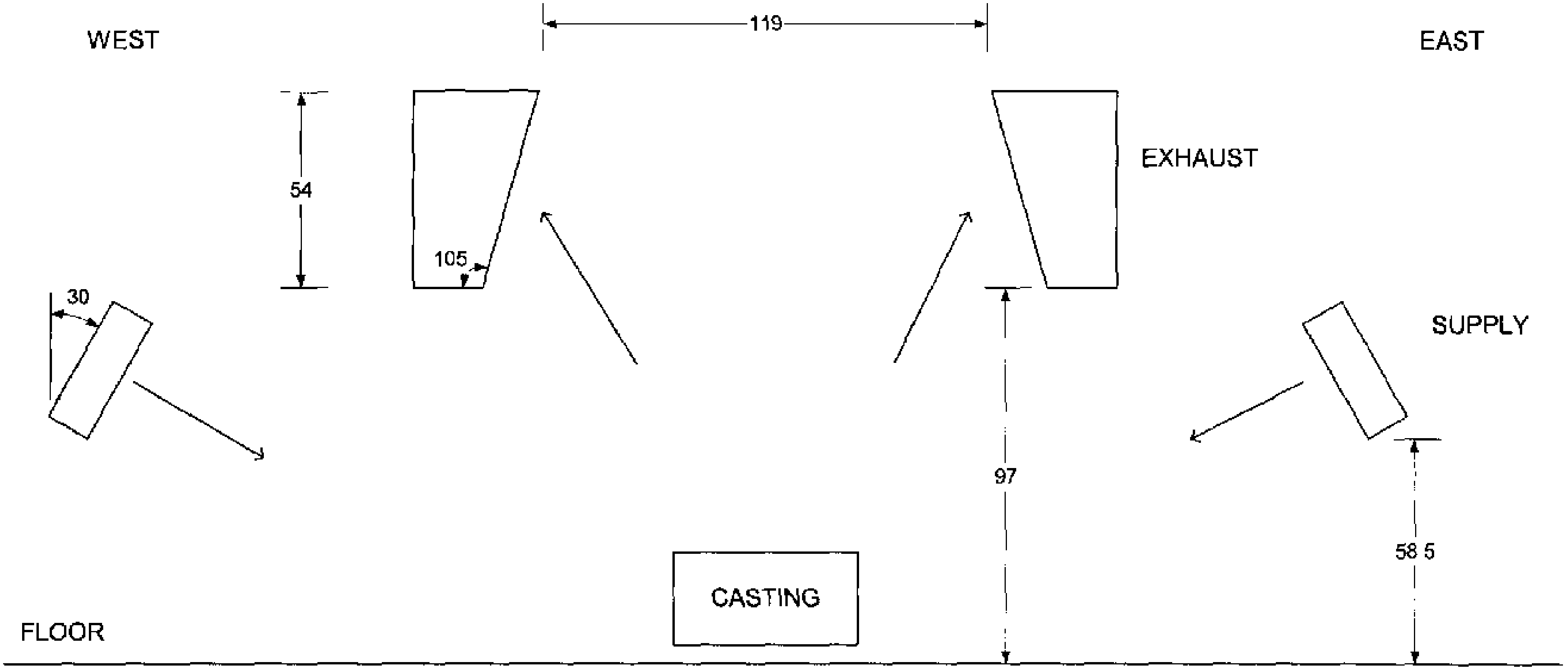


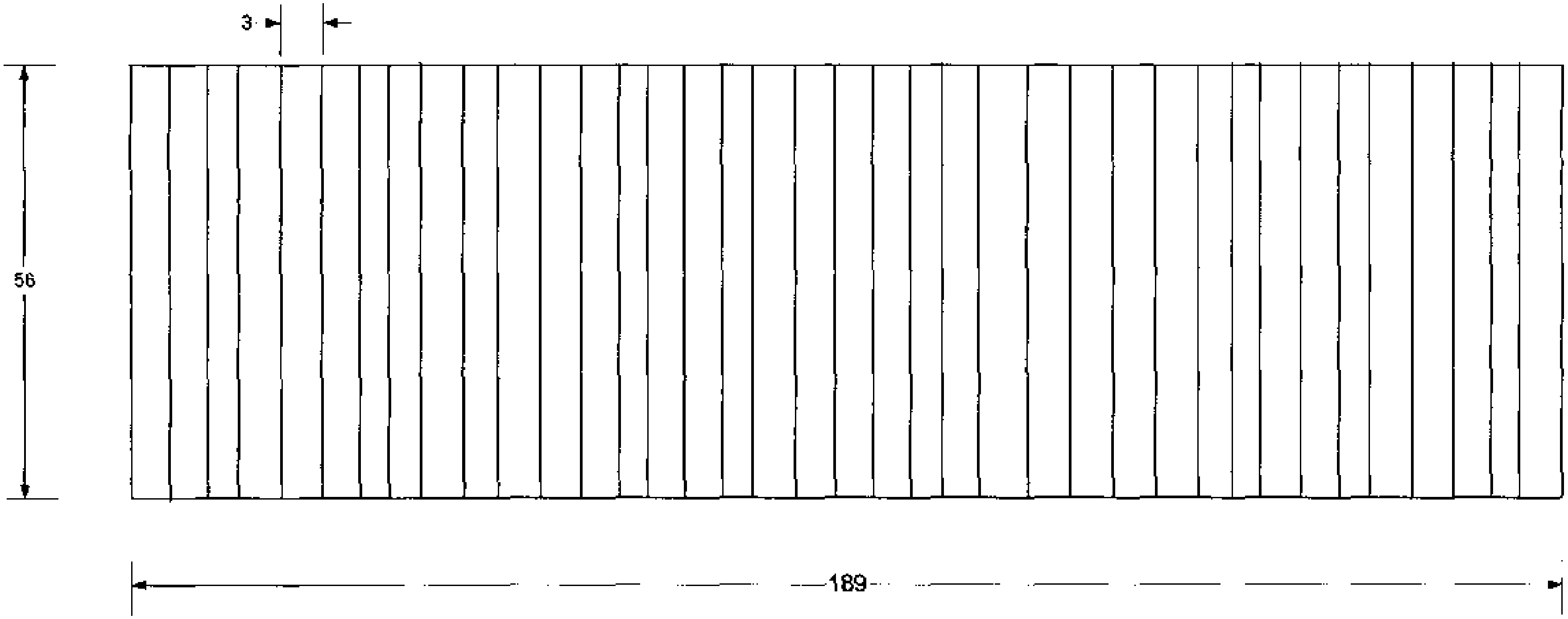
Figure1 Existing ventilation system Supply and exhaust hoods

TITLE
SHAKE-OUT 3

DESCRIPTION
LENGTHS IN INCHES
ANGLES IN DEGREES

SCALE
1 40

EXHAUST HOOD



SUPPLY HOOD

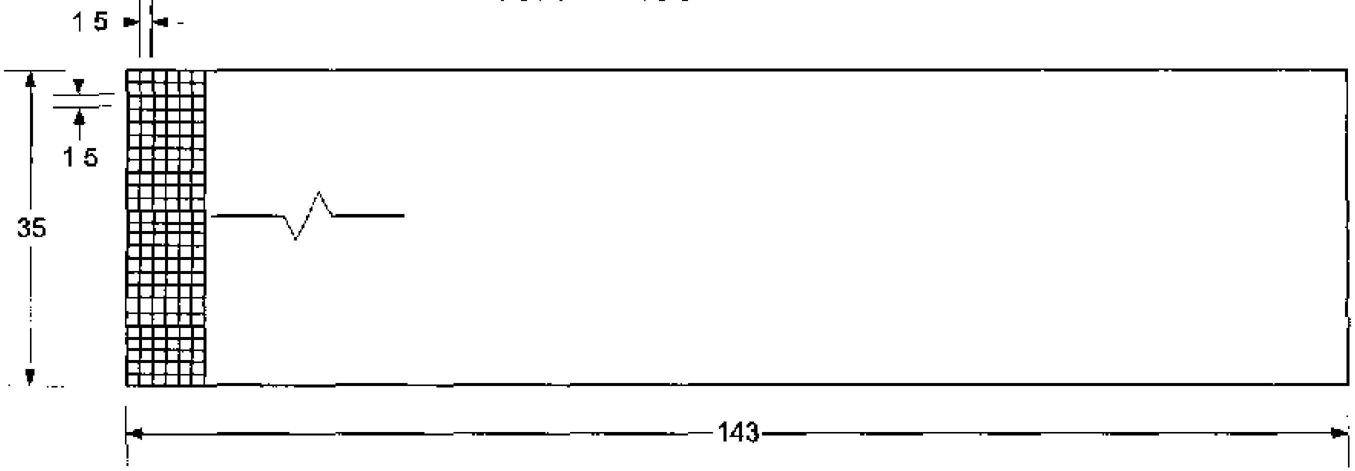


Figure 2

SCALE
1 22 4

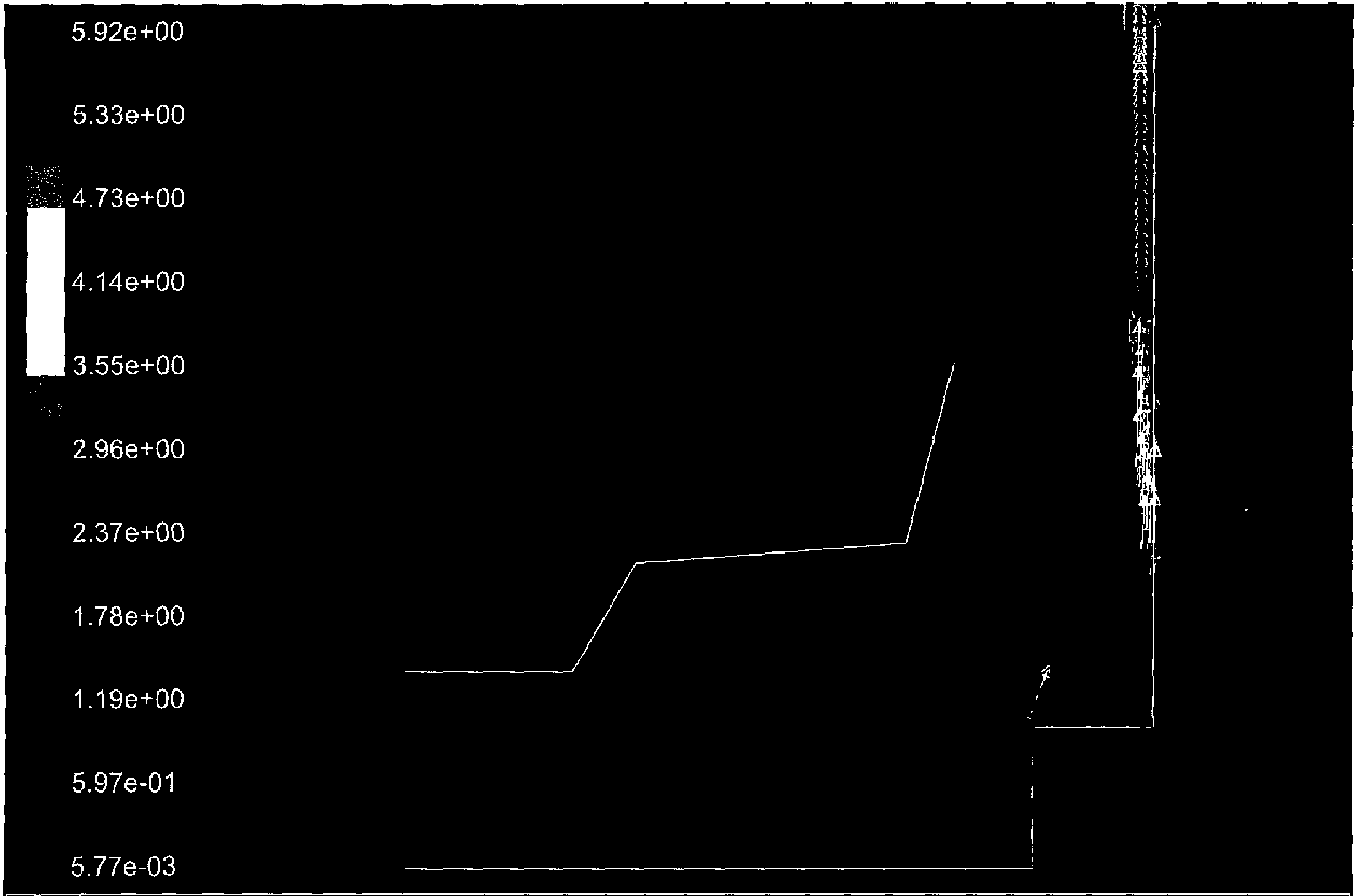


Figure 3. Natural convection only. Velocity vectors colored by velocity magnitude (m/s)

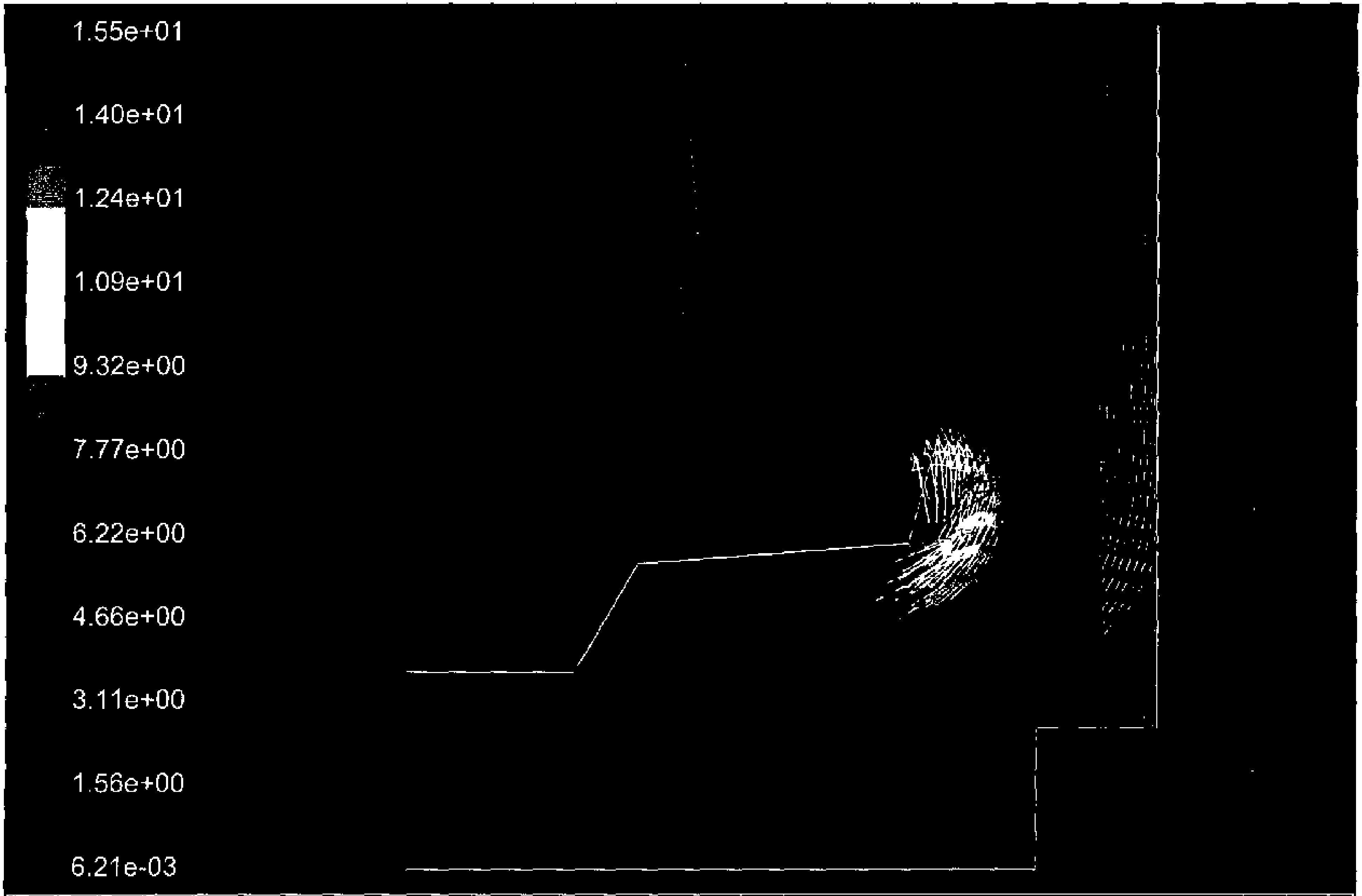


Figure 4. Existing ventilation system. Velocity vectors colored by velocity magnitude (m/s).

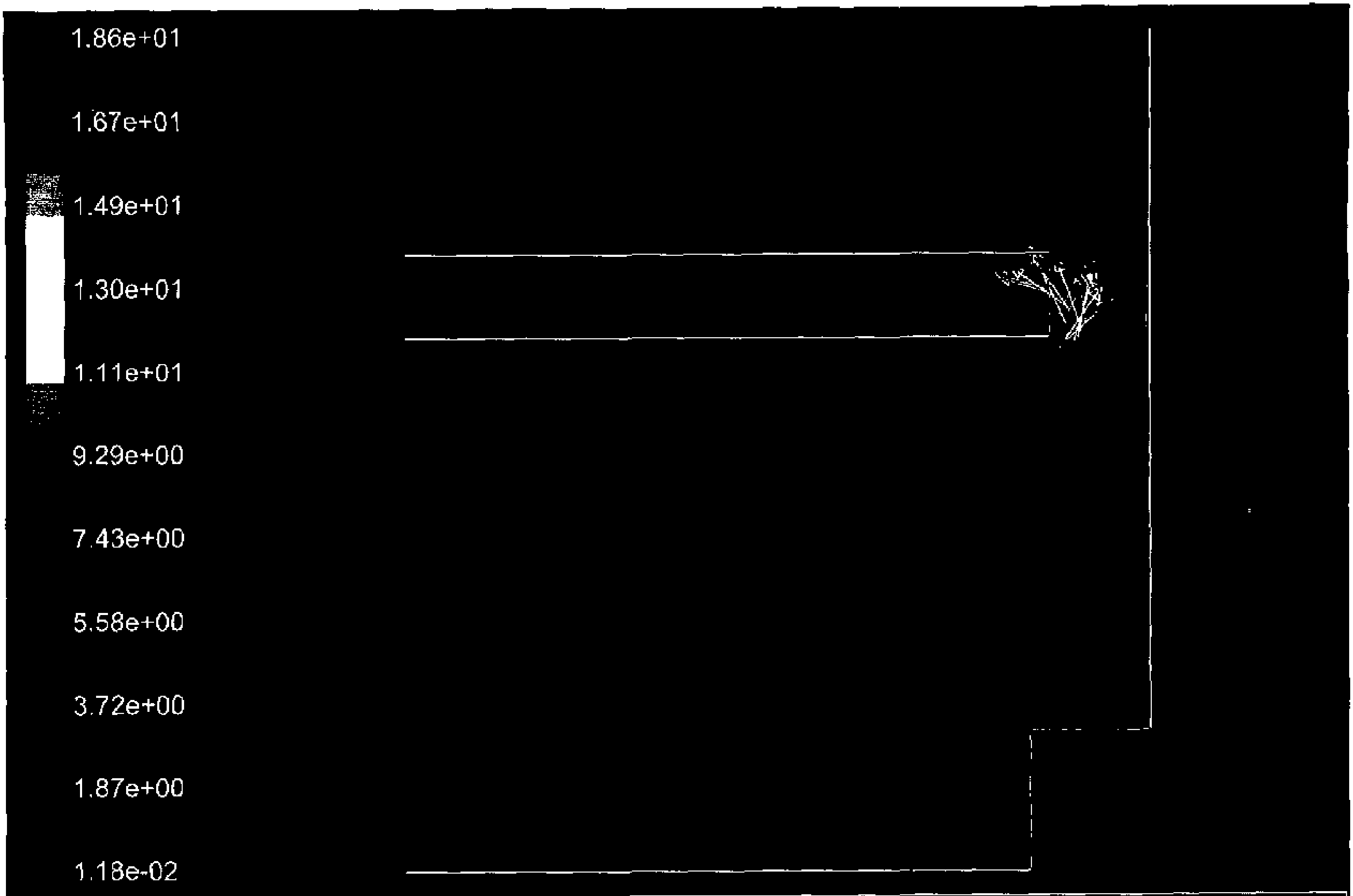


Figure 5. Proposed ventilation system. Velocity vectors colored by velocity magnitude (m/s).

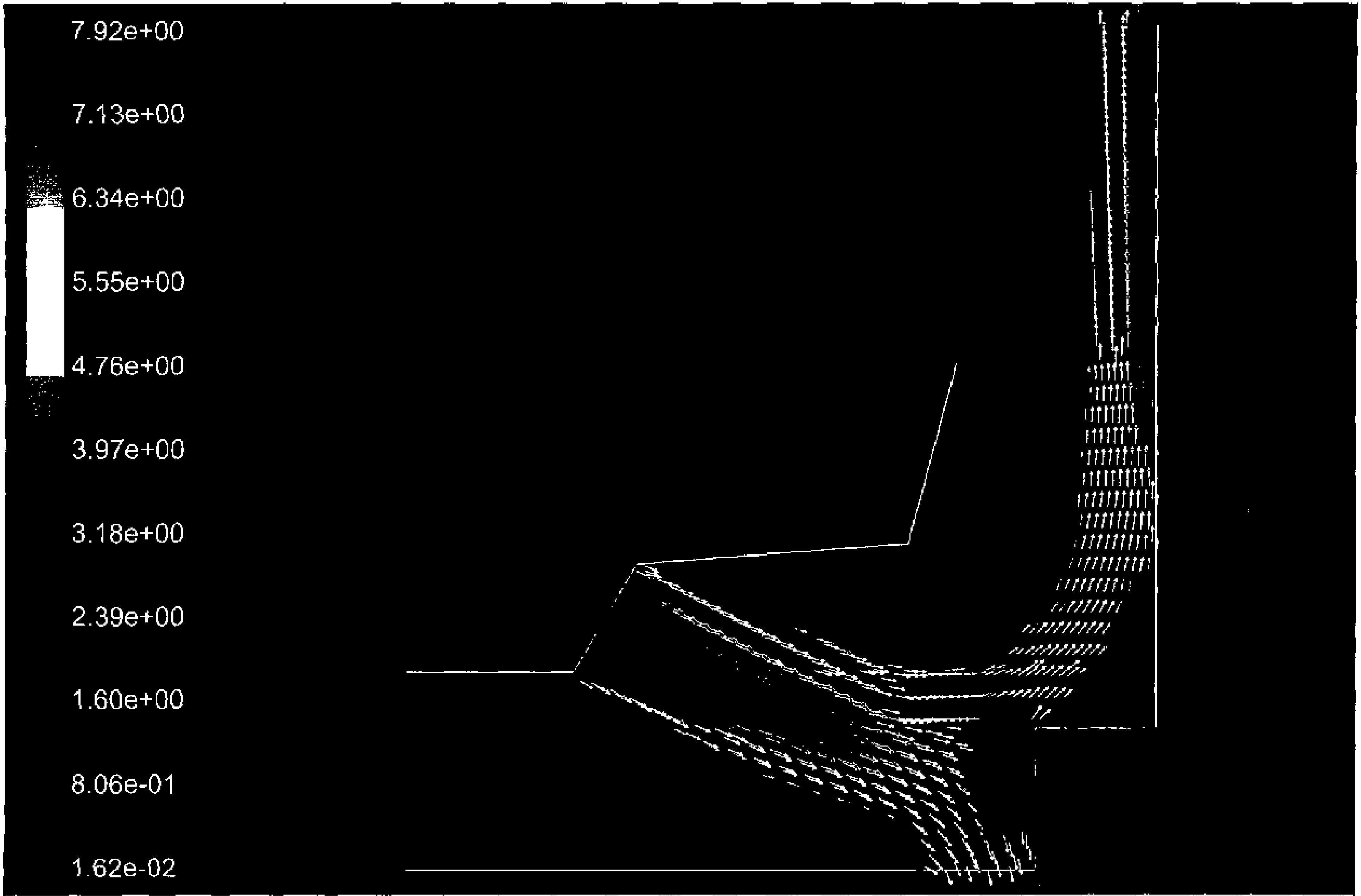


Figure 6. Hybrid: existing supply with floor exhaust. Velocity vectors colored by velocity magnitude (m/s).