JP1.20

WIND TUNNEL EVALUATION OF VEGETATIVE BUFFER EFFECTS ON AIR FLOW NEAR SWINE PRODUCTION FACILITIES

Thomas J. Sauer[1*], Fred L. Haan, Jr.[2], John C. Tyndall[3], Guillermo Hernandez-Ramirez[1], Steven L. Trabue[1], Richard L. Pfeiffer[1], and Jeremy W. Singer[1]
[1] USDA-ARS, National Soil Tilth Laboratory, Ames, IA
[2] Department of Aerospace Engineering, Iowa State University, Ames, IA
[3] Department of Natural Resource Ecology and Management, Iowa State University, Ames, IA

1. INTRODUCTION

Increasing concerns about odor transport from swine production facilities have substantiated both field and laboratory studies on air flow dynamics near these buildings (Mavroidis et al., 2003; Aubrun and Leitl, 2004b). Odor constituents include ammonia, hydrogen sulfide, and various volatile organic compounds (VOCs), which may exist as individual gaseous compounds or adsorbed onto particulates (Zahn et al., 1997; Trabue et al., 2006; Tyndall and Coletti, 2006). Building type, animal diet, facility management, and climate may potentially affect the amount of odor constituents generated at swine facilities. Vegetative cover, local weather conditions, and topography may determine the amount of odor constituents transported from swine facilities. There is an urgent need for designing mitigation strategies to reduce either swine odor generation or transport or both.

Prevailing wind direction and speed, and air turbulence are driving factors of odor dispersion around confined feeding operations. Vegetative buffers planted upwind of confined swine facilities may modify air flow dynamics around buildings by decreasing wind speed, and hence diminishing transport of odor constituents. Vegetation is also capable of physically trapping particulates and odor constituents intersecting them as they flow through the plant canopy (Beckett et al., 2000; Malone et al., 2004). The objective of this wind tunnel study was to assess the effect of vegetative buffer configurations on air flow dynamics around swine facilities.

2. METHODS

Measurements were made in a low-speed wind tunnel (LSWT) located at the National Soil Tilth Laboratory in Ames, Iowa. Previous studies combining both wind tunnel and field measurements have shown that careful wind tunnel experiments provide an accurate and reproducible assessment of field conditions (Huber and Snyder, 1982; Huber, 1989; Mirzai et al., 1994; Aubrun and Leitl, 2004b). Our LSWT has an open circuit design and is capable of air velocities up to 15 m s^{-1} in a control section 0.46 m-tall, 1.22 m-wide, and 5.5 m-long. The floor of the control section was covered with a vinyl mat (Readygrass™) used in model railroad displays that was glued to 1.61 mm-thick (1/8”) sheet metal. The vinyl mat provided a uniform surface roughness with a texture similar in scale to mown grass. In addition to the vinyl mat, five triangular spires (38 cm-tall x 3.5 cm-wide at the base) at the entrance of the control section were used to create a surface boundary layer with appropriate characteristics (Irwin, 1981).

Our building models were constructed of pine wood with dimensions of 80 mm-wide, 530 mm-long, 16 mm-tall side walls, 4 mm-overhang, roof slope of 4/12, and peak height (H) of 31.75 mm. These models scale to swine finisher buildings approximately 40 ft-wide and 200 ft-long with 8 ft side walls, a 15.8 ft peak height and foundation 2 ft above-grade.

Experiments were done at air velocity of 2, 5 and 10 m/s, and measuring velocity profiles (2 to 400 mm above the floor of LSWT) with a constant temperature anemometer equipped with a 1-D boundary layer hot film probe (IFA 300™, TSI Inc., Shoreview, MN) located downstream from the building models at horizontal distances of 1, 2 and, 6 times the height of the building models (1H, 2H and 6H, respectively). Measurements were recorded directly behind the building models as well as midway between building models. Air flow was monitored for 26 sec. at each point and a scan rate of 10 kHz similar to Sauer et al. (2006).

[*] *Corresponding author address:* Thomas J. Sauer, National Soil Tilth Laboratory, 2110 University Blvd., Ames, IA 50011-3120; e-mail: tom.sauer@ars.usda.gov

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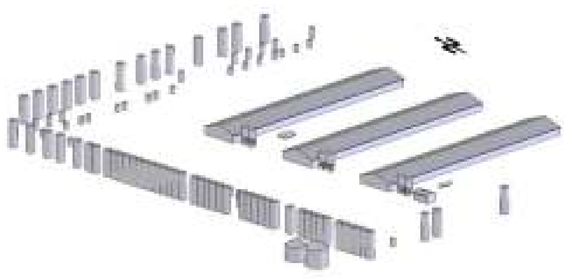

Fig. 1. Model of a swine facility located in Boone County, IA. Prevailing wind direction from southwest in summer and northwest in winter. Rows of cylinders west and north of the buildings represent windbreaks (see description below).

A total of 117 LSWT runs were done to simulate air flow around a swine farm evaluated as a case study (Fig. 1). Three different upstream vegetative buffer configurations were simulated: three rows of trees (first row of willow trees plus two rows of jack pine/eastern red cedar trees), a single row of Austree willow trees, and a single row of hardwood deciduous trees (both scenarios with equivalent total frontal area). All tree scale models (1:150) were constructed using 8 x 8 wire mesh (Aubrun and Leitl, 2004a). Both willow and hardwood models were 60 mm tall while, pine/cedar tree models were between 14 to 24 mm tall. To simulate differences in canopy among tree species, willow/cedar/pine models had a complete double mesh, while hardwood tree models had double mesh only in the upper one-third of the model. All model arrangements were placed in the center of the control section ~3 m downstream from the spires.

3. RESULTS

Air flow dynamics downstream of the swine facility was highly affected by sampling position relative to building models (behind vs. between, Fig. 2). Building models alone had a large impact on decreasing wind velocity. A minimum 20 % of velocity reduction was observed under any of these two scenarios. Measurements done behind the middle building showed a velocity reduction of about 10% compared to values measured midway between buildings (Fig. 2). However, those differences disappeared at heights above the buildings (peak= 15.8 feet) supporting the definitive impact of buildings on air flow dynamic around swine housing units.

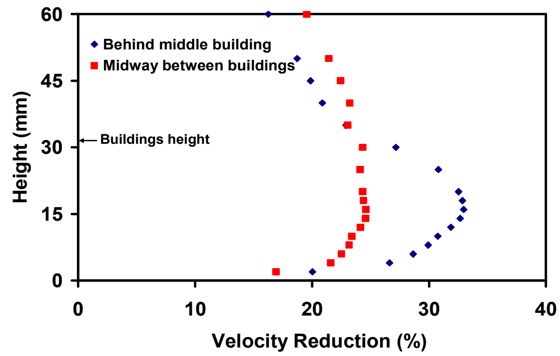

Fig. 2. Wind velocity reduction due to building models with two sampling positions. Models were oriented parallel to air stream.

Our model study demonstrated the potential impact of vegetative buffers to substantially reduce air velocity. Fig. 3 shows how both three rows of trees or a single row of willow trees can decrease air velocity twice as much as the buildings alone from the ground surface to 50 feet height (0 to 100 mm in our model scale).

The effect of the windbreak models on turbulence intensity is much more pronounced than building models alone (Fig. 4). Irrespective of sampling position, the contribution of windbreaks to turbulence intensity was found to be 15 to 20 % greater than the contribution of buildings alone (Fig. 4). In both air flow parameters (wind speed and turbulence intensity), a single row of hardwood trees showed an intermediate effect when compared to buildings alone and to buildings plus three rows of trees or single row of willow trees.

In general, the air-flow distortion effect of both buildings and trees on both air velocity (Fig. 3) and turbulence intensity (Fig. 4) was observed in heights below 100 feet (200 mm in our experimental scale). Even more important, the impact of buildings on air flow parameters (air velocity reduction and turbulence intensity) goes only to a height of 50 feet (100 mm in our experimental scale); however, the combined distortion effect of buildings plus tree rows of trees persists until a height of 100 feet (200 mm in our experimental scale). This air velocity reduction and enhanced turbulence intensity caused by windbreaks may have significant beneficial effects on mitigating odor transport. However, further scale model runs and field research are needed to demonstrate the extent to which transport of odor constituents and particulate matter from swine facilities can effectively be reduced under broader conditions.

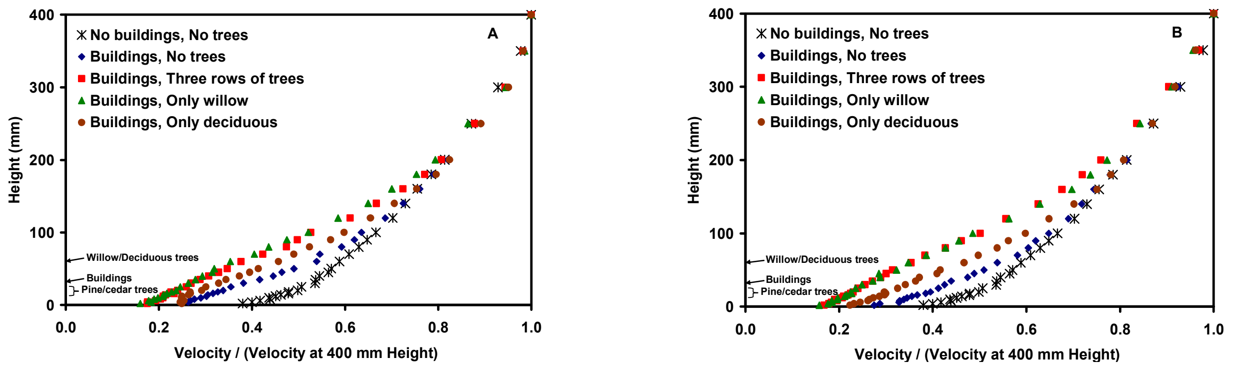

Fig. 3. Air velocity ratio profiles as affected by vegetative buffer configuration at a distance of 6H downstream from the building models at 10 m/s. (A) Behind middle building, and (B) midway between buildings sampling positions. Building models were oriented parallel to the air stream in these experiments.

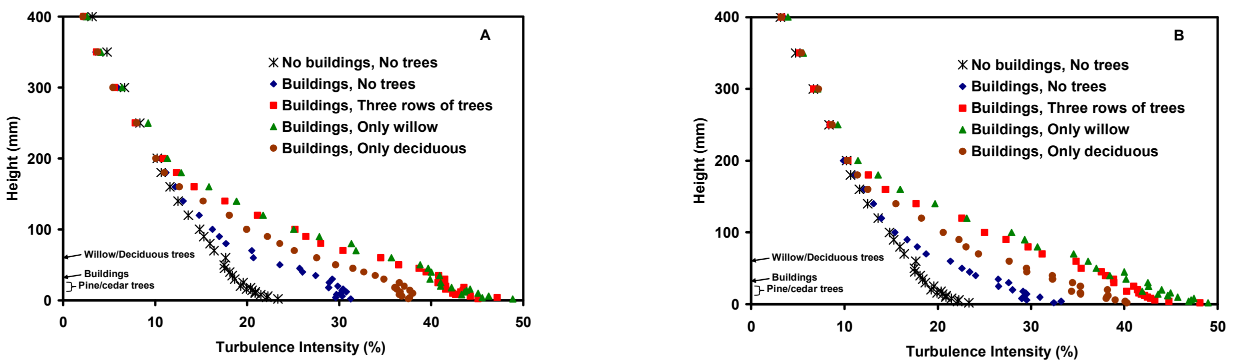

Fig. 4. Turbulence intensity profiles as affected by vegetative buffer configuration at a distance of 6H downstream from the building models at 10 m/s. (A) Behind middle building, and (B) midway between buildings sampling positions. Building models were oriented parallel to air stream in these experiments.

4. CONCLUSIONS

Results of these scale model wind tunnel experiments suggest that implementation of vegetative buffers planted upwind can sharply decrease air velocity, and therefore enhance air quality by reducing transport of odor constituents and particulates from swine confinement facilities. In addition, it is remarkable that a vegetative buffer of a single willow tree row appears to have nearly the same positive effect as three rows of trees (1 willow + 2 cedar/pine). However, other factors such as longevity of tree specie may determine the design of vegetative buffers. This wind tunnel study also indicated the pronounced localized effects of swine finisher buildings on air flow characteristics. Additional considerations about spatial arrangement of windbreaks and buildings may be addressed in future research.

5. ACKNOWLEDGEMENTS

The authors wish to recognize financial support from the National Pork Board (Grant # 07-048) and technical assistance from Jadon Kool, Kevin Jensen, and Dan West.

6. REFERENCES

Aubrun, S., and B. Leitl. 2004a. Development of an improved physical modeling of a forest area in a wind tunnel. Atmospheric Environment 38:2797-2801.

Aubrun, S., and B. Leitl. 2004b. Unsteady characteristics of the dispersion process in the vicinity of a pig barn. Wind tunnel experiments and comparison with field data. Atmospheric Environment 38:81-93.

Beckett, K.P., P.H. Freer-Smith, and G. Taylor. 2000. Particulate pollution capture by urban trees: effect of species and windspeed. Glob. Change Biol. 6:995-1003.

Huber, A. H. 1989. The influence of building width and orientation on plume dispersion in the wake of a building. Atmospheric Environment 23:2109-2116.

Huber, A. H., and W. H. Snyder. 1982. Wind tunnel investigation of the effects of a rectangular-shaped building on dispersion of effluents from short adjacent stacks. Atmospheric Environment 16:2837-2848.

Irwin, H. P. A. H., 1981: The design of spires for wind simulation. J. Wind Eng. & Indust. Aerodyn., 7, 361-366.

Irwin, H. P. A. H., 1981: The design of spires for wind simulation. *J. Wind Eng. & Indust. Aerodyn.,* 7, 361-366.

Malone, G., G. Van Wicklen and S. Collier. 2004. Efficacy of Trees to Capture Emissions from Tunnel Ventilated Poultry Houses. Proceedings to International Poultry Scientific Forum. Jan. 27, 2004.

Mavroidis, I., R. F. Griffiths, and D. J. Hall. 2003. Field and wind tunnel investigations of plume dispersion around single surface obstacles. Atmospheric Environment 37:2903-2918.

Mirzai, M. H., J. K. Harvey, and C. D. Jones, 1994: Wind tunnel investigation of dispersion of pollutants due to wind flow around a small building. *Atmos. Environ.,* 28, 1819-1826.

Sauer, T.J, J.L. Hatfield, F.L. Haan, Jr., and J. H. Prueger. 2006. A Wind Tunnel Study of Flow Characteristics near Model Swine Production and Manure Storage Facilities. Boundary Layers and Turbulence. 17th Symposium, San Diego, CA.

Trabue, S.L., K. Scoggin, F. Mitloehner, H. Li, R. Burns, and H. Xin. 2006. Volatile sulfur compounds associated with animal feeding operations. Atmospheric Environment (in review)

Tyndall, J.C. and J.P. Colletti. 2006. Mitigating Swine Odor with Strategically Designed Vegetative buffer Systems: A Review. *Agroforestry Systems*. Accepted August 1, 2006. Published online: 22 September 2006.

Zahn, J.A., J.L. Hatfield, Y.S. Do, A.A. DiSpirito, D.A. Laird, and R.L. Pfeiffer. 1997. Characterization of volatile organic emissions and wastes from a swine production facility. J. Environ. Qual. 26:1687-1696.