



*The Society for engineering
in agricultural, food, and
biological systems*

*Paper Number: 034090
An ASAE Meeting Presentation*

Temperature and Humidity in Indoor Riding Arenas during Cold Weather

Eileen Fabian Wheeler, Associate Professor

Jennifer L. Zajackowski, Sr. Research Technologist

Agricultural and Biological Engineering

Nancy K. Diehl, Assistant Professor

Dairy and Animal Science

The Pennsylvania State University

University Park, PA 16802

**Written for presentation at the
2003 ASAE Annual International Meeting
Sponsored by ASAE
Riviera Hotel and Convention Center
Las Vegas, Nevada, USA
27- 30 July 2003**

Abstract. *Improved environment within horse-riding indoor arenas starts with an understanding of current conditions. Little information is available on environmental conditions within indoor arenas. Improved rider, instructor and horse comfort and health may be achieved with improved fresh air entry and distribution within the arena. Six indoor arenas were monitored with electronic temperature and humidity sensors in order to better define conditions within the facilities. There was large variation in the amount of ventilation (0, 0.3, 0.4, 1.4, 9.1 and 21.5 m³ opening per 100 m³ arena floor area) provided to indoor arenas for air quality and occupant comfort during winter conditions. The facilities are characterized in terms of a number of features, such as ventilation system, riding surface material, temperature and humidity levels, and management expertise. All but one arena met natural ventilation temperature guidelines most of the time; two arenas met well-ventilated temperature guidelines all the time. All but one arena was more humid, in terms of absolute humidity, than outdoor conditions. Moisture comes from water that is applied to suppress dust in the riding surface. Arenas attached directly to the horse stable had higher indoor humidity levels than arenas separated from the stable.*

Keywords. Horse, Ventilation, Environment, Sensors, Humidity, Temperature

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Introduction

Horses are the second leading agricultural enterprise in the state of Pennsylvania. As the state's horse industry grows, more facilities are turning to indoor riding arenas to lengthen the training season in the northern climate. During a Pennsylvania Department of Agriculture (PDA) study of horse barn and indoor riding arena environments, it was discovered that indoor arenas were more humid than outdoor conditions during cold weather (Wheeler et al., 2001b). It was surmised that the indoor humidity was generated from the common management practice of wetting the riding arena surface, or footing material, for dust control. The small number of horses at any time using an arena would not generate high levels of moisture and high moisture was seen even when no horses were present in the arena.

The humid environment has implications for not only horse health, but also building longevity. Disease pathogens are more abundant in a humid environment, and horses (and humans) are more prone to inhaling the vectors deeper into their lungs as they exert themselves during exercise. Many indoor arenas suffer from chronic dust problems as the footing material dries and is then stirred into clouds of dust from horse hoof action. Common dust management practice is to thoroughly dampen the footing material to add weight to the small, light-weight dust particles and to help bind particles together.

Various microbes, molds and fungi are suspected to inhabit the damp arena footing materials due to the presence of their two basic requirements for growth, nutrients and moisture. Aerial endotoxin levels on riding arena dust can be similar to those reported to cause respiratory disorder in other work environments (Barton et al., 2001). Riding instructors and trainers who primarily work in indoor arenas are twice as likely to show signs of chronic bronchitis as their outdoor colleagues (Kollar et al., 2000). Dust, condensation, and high aerial moisture levels require that building structural components be selected to withstand indoor arena conditions that are more similar to an outdoor versus an indoor climate.

Ventilation might be one of the most over-looked requirements of horse facilities partly because horses have different environmental requirements as they are maintained for longevity and athletic performance (Briggs, 1998; Clarke, 1987; Golden et al., 2000). Others suggest that the trend toward insufficient ventilation is a combination of misunderstood ventilation principles and misguided attempt to provide human-comfortable versus horse-comfortable conditions (Sainsbury and Rossdale, 1987; Wheeler, 2003). Much is written on the importance of good stable air quality (such as Rossdale, 1988; Clarke, 1987) and its impact on equine respiratory health and athletic ability yet very few studies have documented air quality conditions within indoor riding arenas.

Much is known about ventilation strategy and design (such as Riskowski et al., 1998) and ventilation impact, through air quality, on animal performance (Wathes et al., 1983; Clarke, 1987). A comprehensive evaluation of temperature, humidity and other ventilation parameters in indoor arenas would be useful in establishing modern ventilation recommendations. Wheeler et al. (1999) have demonstrated the feasibility of using small, low-cost temperature and humidity sensing and recording devices in livestock housing. The objective of the study reported here was to characterize ventilation systems on indoor riding arenas and collect background information on aerial environment conditions in the arenas during cold weather conditions.

METHODS

Six commercial horse boarding and training facilities in central Pennsylvania were selected based on indoor arena characteristics and geographical location, with all being in one long

agricultural valley. The facilities feature a number of characteristics seen in indoor arena construction and management, including proximity to stable, wind exposure, ventilation system, footing material, and management expertise (Table 1). An initial site visit was used to familiarize the project personnel with the arenas and management practices. A standardization of monitoring locations was determined. The arena and facility layout was characterized, measured and diagramed.

All the indoor arenas used natural ventilation for air exchange. Ventilation openings consisted of combinations of ridge and eave openings, cupolas and sidewall curtains (each site is described more carefully below). Two of the arenas were directly attached to the horse stable and did (Site 1) or could (Site 3 when doors were open between arena and stable) share common airspace with the horse stable environment. The other four arenas were separate structures from the horse stabling. None of the arenas had supplemental heating systems. Temperature above outdoor ambient could be caused by solar load on the minimally insulated roofs, sunlight entry through translucent panels or curtains at the top portion of arena sidewalls (where applicable), artificial lighting, waste heat, or air exchange with an adjoining stable (where applicable). Typically the animal sensible heat contribution to arena temperature would be minimal with only one to perhaps six horses at a time in such a large structure.

An estimate of the ventilation opening size of each arena is included in Table 1. Total opening sizes ranged from 0.3 to 9.1 m² of opening per 100 m² of arena floor area (3 to 91 ft² per 1000 ft²), with two exceptions. One arena provided no cold weather openings with ridge vents and access doors all closed tightly. The second exception was a curtain sided arena that was kept fully open for 21.5 m² opening per 100 m² arena floor area (215 ft² per 1000 ft²). Ventilation opening size was estimated from dimensions at each facility and then adjusted, if necessary, for treatments over those openings, such as window screens (66% open area) or perforated soffit material (5% open area) that inhibit airflow as characterized in Wheeler, 2003.

Each arena had a different riding surface, or footing material. They are more fully characterized in each site's description, below. Arena footing material with high moisture content, and especially when combined with high organic content, would be most at risk for increased indoor humidity. The six studied arenas had a wide range of footing material conditions ranging from a moist, organic stall waste (35% moisture content (m.c.) and 85% organic) to a dry, inorganic washed sand (1% m.c. and 3% organic). The other organic footing, wood chips at 67% organic, was kept rather dry at 14% m.c. The three inorganic footings were kept rather dry at 1 to 5% moisture content.

For the purposes of this study, factors such as manager experience with the footing material and dust control practices were noted in relation to effects on footing materials and hence, the temperature and humidity environment in the indoor arena. Poor drainage characteristics at a site could contribute to increased dampness in the indoor riding arena. During the study period reported here, the outside ground was frozen so that migrating ground dampness was not considered in the analysis of arena humidity and temperature.

Exposure to wind is noted in each facility description as a factor for a natural ventilation system performance. Although reported here, wind exposure is of more importance for cooling summer breezes than during cold weather when the large ventilation openings are kept closed on the arena. Nonetheless, winter wind will aid air exchange on these arena openings.

Temperature (T) and relative humidity (RH) were measured with Hobo Pro units [Onset Computer Corporation, Pacasset, MA; +/-0.4°C [±0.7°F] and +/-3% RH in standard resolution mode at temperature range under study]. These were battery powered, wireless sensors with

integral datalogger for recording conditions. A fifteen-minute data collection interval was used with data downloaded every ten-days from the sensor unit to a laptop computer. A Hobo Pro also monitored outdoor temperature and humidity as a comparison to the indoor environment. This outdoor sensor was mounted near each indoor arena, housed in an OnSet radiation shield. Absolute humidity (AH) was calculated from RH and T data and was chosen for analysis to provide a more consistent comparison of the actual amount of water in the air than using RH. RH analysis is confounded by its dependence on temperature.

Three sensor units were installed in each arena, and one outdoors, at the beginning of December, 2000 and removed on 2 January 2001. Sensors recorded data over the winter holiday break to evaluate conditions during a hypothesized time of heavy riding arena use. In the previous study of indoor arenas (Graves et al., 2001), it was determined that attaching sensors to the arena north sidewall did not provide good representation of arena conditions. Condensation on the exterior wall biased the sensor readings. Therefore, in this study, one sensor was located along the north sidewall for comparison to previously collected data while the other two sensors were placed near the center of the arena on separate jump “standards” (five facilities) or round pen panels (Site 4). One chosen standard or panel sensor location was in the center of the arena and the other nearer the sidewall. Location of the standards was not guaranteed to remain the same for the length of the project, however, in four of the five facilities the standards with sensors were not moved. The round pen panels were stationary. An additional datalogger was installed in the horse stable of each facility, at a central location in the horse-occupied area. Data were used to compare to riding arena conditions and to determine sources of heat and moisture for the two arenas with attached stables.

To aid in the analysis, a 72-hour time period was selected for a “study period” based on the criteria of cold temperatures and hypothesized heavy arena use. This time period selected and analyzed was Friday, 21 December through Sunday, 23 December 2000. Not only was this a holiday weekend but also one of the coldest during the study period, with average temperatures across all six facilities ranging from -16.3 to -3.9°C ((2.6 to 25.0°F) night 22-23 Dec to midday 21 Dec.). All observations reported here were based on data from this 3-day period.

Table 1. List of site characteristics, ventilation parameters, and footing material characteristics of the six monitored indoor riding arenas.

Facility	Size m (ft)	Wind Exposure	Ventilation Openings used During Study Period ³	Ventilation Opening ³ Size m ² per 100 m ² Arena Floor Surface (ft ² per 1000 ft ²)	Footing Material	Footing Moisture (%) & [Organic Matter ⁴ (%)]
Site 1	45.7x19.5 (150x64) attached ¹	Sheltered	Eave & Ridge Openings	9.1 (91)	Stall Waste	35 [85]
Site 2	48.8x18.3 (160x60)	Sheltered	Curtains, Eave Openings & Cupolas	21.5 (215)	Hardwood Chips	14 [67]
Site 3	18.3x45.7 (60x150) attached ¹	Exposed	Eave & Ridge Openings	0.4 (4)	New Limestone Gravel	2 [7]
Site 4	45.7x32.9 (150x108)	Sheltered	All Openings Closed	0 ²	Worn Quartz Sand	5 [5]
Site 5	48.8x21.3 (160x70)	Sheltered	Eave Opening & Cupolas	0.3 (3)	New Quartz Sand	1 [3]
Site 6	36.9x18.3 (121x60)	Exposed	Eave & Ridge Openings	1.4 (14)	Limestone Sand & Wood Shavings	10 [20]

¹ Arena attached to stable with access to stable aerial environment.

² All arenas subject to infiltration air exchange via gaps around doors, panels, curtains, etc. Site 4 had no open ventilation openings during the study period.

³ Ventilation openings and size are those used during the December study period. Additional openings are available for mild and hot weather ventilation.

⁴ Average values from 9 footing samples collected in each arena 5 or 8 December, 2000. Conditions within the arena during the study may be considered similar for organic matter content but not necessarily for moisture content.

Facilities Monitored

Site 1: Attached Indoor Arena with Eave Inlets and Residential Ridge Vent, Stall Waste Footing

An attached (perpendicular) 45.7 by 19.5 m (150 by 64 ft) indoor arena was added on the south end of the stable. The stable was originally a two-story beef/dairy bank barn converted for horse use in 1985. Twenty-four stalls were located in the original barn structure and four stalls were added in the transition between the indoor arena and the original barn structure. The arena and stable shared a common air space at all times. During the monitoring period, the facility stable was over 90% full. This facility was an active boarding, lesson, and training facility specializing in the hunter-style discipline.

The arena frame was wood with metal siding and an un-insulated metal roof over wooden trusses. Arena ventilation was provided year-round through 10.2 cm (4 in.) eave inlets and a continuous commercial-style ridge vent, with an estimated 2.5 to 5.1 cm (1 to 2 in.) of opening. Hardware cloth was installed at the eave inlet openings. Not used during our study period, but present for warmer weather ventilation were 3.7 by 3.7 m (12 by 12 ft) sliding doors located in each end wall, 7 m (23 ft) from the south wall of the arena. On the north side, two 3.0 m wide by 2.7 m high (10 ft by 9 ft) sliding doors provided access to the double-aisle stable. In warm weather, all four arena doors were opened to allow more air exchange. The facility owners built the arena themselves from modified commercial plans.

Heaviest use of the arena was in the evenings and weekends. A 0.6 m (2 ft) high translucent panel located just under the eave provided natural light for the arena. Daylight riding hours were extended through artificial lighting. Fluorescent lighting in the indoor arena, mounted on the bottom truss chord, consisted of two rows of four 2.4 m (8 ft) fixtures, 4.9 m (16 ft) in from the sidewalls.

Arena footing consisted of fresh stall waste (shavings and manure), which was dark in color and loose in texture. The arena footing was removed to expose the packed clay base and replaced completely every 3 to 4 years. In the winter 3 to 4 spreader loads were added per week to help replace the footing that was packed and broken down from the heavy horse traffic. When arena use lessens, stall cleanings were spread for two weeks in summer (approximately 12 spreader loads). Water, added to footing by a tractor-pulled tank with gravity feed water bar across the back, was added frequently, usually once per week, after which the footing was harrowed. The facility manager/owner had 15-years of experience with the footing and, for the purposes of this study, was considered an experienced manager.

Site 2: Detached Indoor Arena with Sidewall Drop Curtains, Wood Chip Footing

This indoor arena was a separate building built in a flat portion of the property that was in the floodplain of both a seasonal and permanent creek. This facility is approximately 5.6 km (3.5 miles) from Site 1, however, it is more centered and in a wider section of the valley. Wind protection in this area was a great deal less than at Site 1; however, it was still more sheltered than the “exposed” project study facilities.

The 48.8 by 18.3 m (160 by 60 ft) indoor arena, built by an agricultural builder, had 1.8 m (6 ft) high curtains in the upper half (starting at 2.4 m [8 ft] high) of the sidewall height for light and air entry. The curtains were kept open year-round. Bird netting was provided over the open area.

A winch with cable located indoors opened and closed the curtain material. The arena was wood frame construction with wood truss roof support and metal siding. Three cupolas supply ridge air exchange. The eave vents were 20 cm (8 in.) of unprotected open area on a 40 cm (16 in.) overhang and remained open even if the curtain was completely shut. Additional air exchange and arena access was provided through a 4.9 m (16 ft) wide sliding door on the east end and the 0.9 by 2.4 m (3 by 8 ft) walk doors at each endwall. Arena lighting was provided with three rows of high intensity discharge (HID) lights. The east end of the arena had a concrete-floored spectator/storage section.

The arena footing was hardwood chips over a firm base. The arena had no maintenance during the study period and was watered down twice per year by the local fire department. A “track” had developed along the arena wall where horses are ridden “along the rail”. Breakdown of the wood chips was seen from the heavier traffic over that area. Where footing depth was adequate, the surface was bouncy and lighter in color than in most arenas. Footing material was deeper on the west end of the arena.

The stabling facility at this site was a dairy bank barn converted to a stable with sixteen stalls. A newer, “lean-to” type addition, housing eight stalls was added to the east side. At the time of this study, the facility was in the process of being sold and was only one-third full. Ring use was moderate, primarily through the use of lessons in the hunter-style discipline. The manager had several students that utilized facility-owned horses, which accounted for much of the arena use. The manager had only operated the facility for a short time. Management’s experience would be considered novice, as compared to the more experience managers in the study.

Site 3: Attached Indoor Arena with Residential Eave Inlets and Ridge Vent, Limestone Gravel Footing

The third facility was located approximately 16 km (10 miles) southeast of the first two. The arena was attached to the west end of the stable separated by a firewall rated for 2 hours. This facility housed not only a hunter-style discipline boarding and training stable, but also a therapeutic riding program. The stable and indoor arena, constructed in 1995 by a commercial/agricultural builder, housed 31 horses and was estimated to be about 80% full during the study. The arena was located near the top of a hill, on the south-facing slope. Wind potential was much greater than Sites 1 and 3 due to the lack of protective geographic features of the topography.

The arena was an uninsulated metal-sided and roofed building 18.3 by 45.7 m (60 by 150 ft) with wood truss framing and a vertical flakeboard kick panel on the lower 101.6 cm (40 in.) of the 4.9 m (16 ft) tall sidewall. The arena was ventilated through a continuous ridge opening and intermittent eave inlets. Eave soffit openings were covered by 0.3 m (1 ft) square residential-style metal soffit paneling. The soffit panel pattern had eight perforated (openings were dots) panels then two solid panels. The 10.2 cm (4 in.) width of ridge vent opening on inside was covered with diamond expanded metal mesh that leads into a commercial-style ridge vent with an estimated opening of 3.8 cm (1.5 in.). Large doors could be opened in warmer weather along with two 0.9 m (3 ft) wide human door on each long sidewall near the endwalls. Two large east endwall doors could be opened into the aisles of the attached stable so that airspace was shared with the stabled horses.

Natural light was provided on the north and south sidewalls through 0.9 m (3 ft) translucent panels under the eaves. Artificial lighting facilitated the heaviest arena use during evenings and

weekends. Lighting consisted of two rows of seven HID lights and a row of 6 incandescent lights up the center of the arena.

The footing in the arena had been stall waste, which had been stripped down to the unpacked soil base and replaced with small, unwashed limestone gravel. The footing was watered as needed, usually at least once per week, with a garden sprinkler. This manager's experience level would be considered a novice with the new type of footing, however he did benefit from several years of previous indoor arena management experience.

Site 4: Detached Steel-Span Indoor Arena with Manual Ridge Openings, Sand Footing

This facility had several barns and a large indoor arena. The facility was well protected from wind through a grove of trees to the south of the arena and the foaling barn, show barn, breeding office and laboratory buildings on the north side of the arena.

It was unknown exactly when the buildings were built; however, the facility has been in operation over 10 years. Horses were boarded, however it was primarily a breeding and multi-discipline training facility. One of the three barns on the complex was a heated show barn. Horses stalled in the show barn were turned out for exercise in the indoor arena. Sensors were attached to round pen panels that were set up near the center of the arena. The boarding facility was full during the study period, however, the breeding and foaling barns were mostly (estimated 90%) empty. The arena was heavily used during most of the day.

The 45.7 x 32.9 m (150 by 108-ft) indoor arena was the central part of a larger building. The steel rigid-span arena roof was estimated to be 20 feet at the peak. The total building dimensions were 54.9 by 45.7 m (180 by 150 ft). To the west of the arena was a 12.2 m (40-ft) wide open-fronted shed, used to store vehicles and equipment. On the east side was a 9.8 m (32-ft) wide enclosed, heated, and insulated shop. A section of the northwest corner of the shop was converted to a heated wash stall. The arena had fiberglass insulated exterior walls and roof.

Arena ventilation consisted of a series of commercial-style ridge vents, that could be opened manually, and large endwall doors. Six 6.1 m (20 ft) wide, 4.3 (14 ft) high, doors (three per exterior wall) could be opened in the summer for air exchange. In the winter the building ridge vents and doors were kept closed except for the occasional opening of door for arena entry. Some small opening could be detected at each ridge vent, appearing to be construction gaps that allow air infiltration. Although the shop on the east side of the building was heated, the heat was used sporadically when the shop was being used.

As seen in a preliminary study (Graves et al., 2001), this arena was significantly warmer than outdoor air, being warmer than any other arena in the study, and it was suspected that heat from the adjacent shop through an uninsulated metal wall was the primary cause. Four rows of six translucent panels were installed in the roof. These provided natural light and the light colored metal walls reflected enough light so that the six rows of four HID lights were not needed during daylight hours. Arena temperatures were well above outdoor conditions even during night hours so the solar gain through roof panels could not account for all arena warmth.

The use of this facility was expected to be very constant throughout the day. Horses were trained by the owner/manager and her employees during the morning and afternoon hours with horses from the heated show barn being turned-out in the arena between training sessions. Lessons and boarded horses were then worked in the arena during the evening.

The arena had a sand footing that had worn to the consistency that resembled a sandy soil rather than pure sand. The footing was watered on Wednesdays (during the study period) and allowed to penetrate for a few days before harrowing. The owner was satisfied with the seemingly low dust level in the arena. The owner is an experienced manager of the indoor arena.

Site 5: Detached Indoor Arena with Residential Eave Inlets and Cupolas, Sand Footing

This facility was the newest facility monitored, being built within the previous year. The 48.8 by 21.3 m (160 by 70 ft) indoor arena was a metal-sided building with 1.8 m (6 ft) curtains on the top half of the east and west sidewalls. Wooden trusses supported an uninsulated metal roof. An 18.3 m (60 ft) wide by 11 m (36 ft) depth open-sided, storage shed was attached on the west sidewall about 12.2 m (40 ft) from the southern end of the arena.

The arena was ventilated during our study with eave inlets and three cupolas. Airflow through the eave was restricted by the addition of punched aluminum soffits, similar to Site 3. The cupola openings were estimated to be about 1.2 m (4 ft) square at the base with 50% of this as open area through the louvers. The cupolas were located at 7.3, 24.4, and 31.4 m (24, 80, and 103 ft) from the north endwall. During warmer weather sidewall curtains and doors could be opened for more air exchange. The sidewall curtains ran the entire length of the east sidewall and on 30.5 m (100 ft) of exposed wall on the west side (to both sides of the attached shed). A small walk-door (1.2 by 2.1 m [4 by 7 ft]) and a larger equipment door (3.7 by 4 m high [12 by 13 ft]) on the south side wall provided the main entrance to the ring. A 3.7 m (12 ft) wide door on the west side provided access to the attached shed. Another 1.2 by 2.1 m (4 by 7 ft) human door was located north of the attached shed. The arena had two rows of five HID lights installed but were not yet connected to the farm electrical service.

The arena footing consisted of washed sand that was watered frequently during the monitoring period to suppress dust. The watering was done by hand via a hose and/or sprinkler. The owners/managers competed professionally in the hunter-style discipline; however, the facility was primarily a boarding facility that offered no training. The barn housed a total of 20 horses and the facility was approximately 80% full during the study period. The site was very well sheltered from wind from the surrounding hills and grove of trees to the west. The owners were new to indoor arena management since their previous property only had an outdoor arena.

Site 6: Detached Indoor Arena with Eave Inlets and Ridge Vents, Limestone Sand and Wood Shaving Footing

This arena was a metal-sided and roofed building with wood truss framing for a 4.3 m (14 ft) arena height. The 36.9 by 18.3 m (121 by 60 ft) indoor arena, constructed in 1985, was sited at the top of a small knob at the southern end of a large hay field. Buildings to the south and east of the arena provided ample wind protection, leaving the north and west exposed. In the winter, the prevailing winds were normally out of the northwest.

The arena had eave inlets and intermittent ridge openings for ventilation. The 22.9 cm (9 in.) soffit opening on the 40.6 cm (16 in.) eave was covered with a residential window-style fly screening. The screen was at least 25% clogged with dust and this was accounted for in the ventilation opening estimate. The residential-style ridge opening had slotted vent holes and a small, raised ridge cap. The 3 m (10 ft) ridge vent sections were alternated with 3 m (10 ft) of solid roof so that about half the arena ridge length was vented. The arena had three exterior

doors for additional ventilation but these were kept closed as much as possible to keep the footing from drying out. A 0.9 m (3 ft) wide human entry door to the south near the stable was the most frequently used with access for large vehicles through 3 m (10 ft) wide doors on the south and west. Natural light was provided by 0.6 m (2 ft) high translucent panels located at the top and along the length of both sidewalls. Nighttime riding was illuminated by two rows of fluorescent lighting.

The footing was a mixture of manufactured limestone sand and pine shavings. Shavings were added to retain moisture since the sand had a tendency to be dusty and dry out quickly. The footing had not been removed since the building was erected; only added to as the need arose. The southwest corner of the indoor had been enclosed for use as a heated observation room, 3 by 3.4 m (10 by 11 feet). The footing in the indoor was watered, as needed, with a garden sprinkler that was moved around to cover the entire footing surface. The sprinkler would be set up to water one spot until the footing was determined to be wet enough by the owner/operator. The operator had a great deal of experience with the footing and managed it by personal observation. No watering was done during the monitoring period due to cold outdoor conditions and the risk of the footing freezing.

The remodeled barn (age unknown) stalled approximately 20 horses and was nearly full during the study period. The arena use was expected to be heaviest during the evenings and weekends. The owner/manager specialized in training hunter-style and most of the horses were boarded.

RESULTS AND DISCUSSION

Criteria of proper natural ventilation were evaluated using guidelines that determine how well the facilities were performing. Factors such as temperatures to within 2.8°C (5°F) throughout the structure indicated uniform air distribution within the interior (Wheeler et al., 2001a). Appropriate air exchange may be linked to maintenance of interior temperature to within 2.8 to 5.5 °C (5 to 10°F) of outdoor T for cold housing (Wheeler, 2003; Huffman, 2001). None of the arenas had supplemental heat so that temperature gain was from another source such as solar gain, electric lights, sensible heat from stabled horses in shared airspace, or the few horses that were exercised in the facility.

Humidity levels were considered acceptable when they tracked the profile of outdoor conditions. Correlation of indoor and outdoor humidity has been observed during times of adequate ventilation in other livestock housing studies (Graves et al., 2001). When inadequate ventilation, or supplemental heat is used, the tracking of indoor to outdoor humidity levels is inconsistent.

Using the above criteria for characterizing ventilation uniformity and indication of air exchange, the six indoor arenas fell neatly into three groups: “well-ventilated” where conditions met or exceeded guidelines at all times, “adequate ventilation” where conditions mostly met guidelines, and “poor ventilation” where conditions commonly did not meet guidelines. Two arenas of the six, Sites 2 and 6, met the criteria for “well-ventilated” based on both temperature and humidity conditions.

Sites 1, 3, 4 and 5 were used heavily, as expected. Sites 2 and 6 were not used at all. Site 2 cited dust problems and the undesirable freezing the footing material if it was watered. Site 6 was not used due to the cold temperatures that made working horses uncomfortable for the humans involved.

Despite the label of “indoor” riding area, conditions within these facilities were almost the same as outdoor conditions and in some ways, even harsher. Indoor arenas have a reputation of being dusty but the data collected during this project confirmed the high humidities found in previous studies. Moisture from the large quantities of water used to dampen dust in the arena footing materials was thought to be the main contributor to the high indoor AH.

A cause-and-effect relationship cannot be established for arena environment based on independent variables such as wind exposure, ventilation openings, and footing material characteristics, due to the inter-connectivity of all the variables. Temperatures in the two arenas exposed to wind (Sites 3 and 6) were within what were considered “adequate” or “well” ventilated, respectively, when compared to outdoor and to each other. The sheltered buildings (Sites 1, 2, 4, and 5) were also considered “adequately-ventilated” during this cold weather study. One (Site 4) appeared to have significant heat addition to the arena since temperature was -13.3 to -7.8°C (8 to 18°F) above outdoor conditions even at night when the arena was not used. Three of the four sheltered facilities were consistently wetter. Since such variability existed, each facility was evaluated based on good cold housing ventilation criteria. Comparisons between facilities were difficult to make.

Temperatures

Temperatures (both indoor and out) at Site 2 were separated by only a few degrees with the difference in T being smaller than the accuracy range of the instrument (1°C, 0.6°F). This building was expected to be well-ventilated as the top 1.8 m (6 ft) of the 4.9 m (16 ft) high sidewall was open with 21.5 m² opening per 100 m² arena floor area (215 ft² per 1000 ft²). This expectation was supported by the fact that there was no T gradient among the sensors. No one sensor was consistently warmer or cooler than the rest. Sensors showed that T in the arena dropped and climbed at the same time the outdoor sensor showed a T change. On two occasions, large T spikes were seen on the sensors hung on the jump standards that were not seen on the sensor hung on the north wall. This was probably a result of the open curtain allowing sunlight on the jump standard sensors. Both events happened just prior to noon on the 22nd and 23rd of December.

Based on a T definition of “good air exchange”, Site 6 falls into the well-ventilated category at 1.4 m² opening per 100 m² arena floor area (14 ft² per 1000 ft²). Air exchange restrictions estimated at 50% of the open area, through the use of window-screening, which had clogged with dust, were overcome during cold weather conditions. Generally the indoor and outdoor T were the same or within 3.6 to 9°C (2 to 5°F) of each other. Overall, indoor T responded quickly to changes in outdoor T. The north-wall temperature sensor was consistently the closest to outside T while the sensors located on standards nearer the center of the arena were consistently warmer.

Three of the facilities, Sites 1, 3, and 5, were adequately ventilated. Indoor T at all three buildings quickly responded to a climb in outdoor T. Conversely, though, all three buildings retained this gained heat and, although they responded in a reasonable time, indoor T did not drop as quickly as it climbed. This trend would be expected to be worse during periods of warm weather and high solar loads.

Temperatures at Site 1 tracked outdoor T consistently with an opening area of 9.1 m² per 100 m² arena floor area (91 ft² per 1000 ft²). The sensor located near the north sidewall was consistently the coolest of the indoor T. The building was quicker to respond to outdoor climbs

in T than outdoor T decreases with the largest difference between indoor and outdoor T, at 2.8°C (5°F), was most frequently seen around the noon-hour of the day. This stable shared airspace with stabled horses so would gain heat from that environment.

Site 3 had the most uniform T across the arena of the adequately ventilated group (figure 1A). Temperature spreads of the three interior sensors were at most 0.8°C (1.5°F). Indoor T trends followed outdoor T but, compared to Sites 1 and 5, the difference between indoor and outdoor T was the most inconsistent. Indoor T responded quickly to a climb in outdoor T on the morning of 21 December, and responded slowly when the outdoor T dropped around noon on 22 December. From approximately 14:00 to 15:00 on 22 December, indoor T increased while outdoor T was decreasing. Consistently during the noon-time hours of the day, the largest difference between indoor and outdoor T was seen. This arena shared airspace with the horse stable when arena doors connecting the two were open. The arena temperature was consistently between outdoor T and stable T.

Except for the first 6-hours of 21 December, Site 5 indoor T tracked outdoor T most consistently of the three adequately ventilated facilities (figure 2A). Temperature was generally within 1.1 to 1.7°C (2 to 3°F) of outdoor T with some nighttime T differences near 2.8 to 3.4°C (5 to 6°F). Uniformity within the facility was usually within 1.1 to 1.7°C (2 to 3°F). The sensor at the sidewall showed the most daily variation in T, being coolest at night and warmest during the day. The two sensors on standards, which were further away from the wall, indicated virtually the same temperature.

The poorest-ventilated facility, based on T analysis, was Site 4, which was expected since all ventilation openings were closed during the study timeframe. Temperatures within this arena were commonly 4.5 to 10.1°C (8 to 18°F) warmer than outdoor T. Project personnel and the facility owner/manager were unable to identify the heat source for this arena. On two occasions, indoor and outdoor temperatures matched, (noon on the 21st of December and 13:30 on the 23rd) during the warmest part of those days. Trends on indoor T were seemingly independent of outdoor T. At 9:30, 22 December, outdoor T had climbed from -6.8°C (19.7°F) to reach -4.3°C (24.2°F). During this time, all three indoor T remained constant, averaging -1.9°C (28.5°F). During a drop in outdoor T from -3.4 to -13.5°C (25.9 to 7.7°F (13:30 to 21:15, 23 December,)) indoor T away for the exterior wall dropped only slightly more than 1.1°C (2°F). A larger T drop was seen at the wall, however, this drop was only about 2.2°C (4°F). Temperature uniformity within the arena was adequate ranging from 0.6 to 2.2°C (1 to 4°F).

Absolute Humidities

The absolute humidity data probably tells more about air exchange than temperature since the latter can be more influenced by supplemental sources. Only one riding arena, Site 2 with the open curtain sidewalls, had indoor AH lower than outdoor AH during the study period. The other arenas all had higher indoor AH than outdoors. In some cases, relative humidity data are discussed in relation to condensing conditions or variability within the arena.

The driest facilities were Sites 2 and 6, neither of which had the footing watered during the 3-day analysis period. With the second and third highest organic matter content of arena footing material, they also had the second and third highest footing moisture contents even though they were not watered. Both buildings were separate from the stabling. Indoor AH mirrored outdoor AH, which was considered a sign of good air exchange, for both buildings. In both these facilities, there was uniformity within 0.10 g/m³ in indoor AH among the three sensor sites, which is within the detection error of the instrument.

Site 2 indoor AH was virtually the same or slightly less, 0.25 g/m^3 , than outdoor AH during night and morning hours. During the afternoon hours of noon to 18:00, indoor AH was up to 0.40 g/m^3 less than outdoors, but on the afternoon of 21 December, indoor AH was up to 1.25 g/m^3 drier than outdoor. In this open facility with relatively dry organic footing material, the indoor RH was 5 to 25% lower than outdoors most of the time even though the temperature was virtually the same indoors and out.

Site 6 indoor AH stayed above outdoor AH during the 3-day analysis period. During the first day of the analysis period (21 December) until 6:00 on the second day, indoor AH was 0.25 to 1.00 g/m^3 wetter than outdoor AH. During the remainder of the study period, indoor AH at Site 6 closely matched outdoor AH, within 0.10 to 0.35 g/m^3 . As a general facility practice, the owner/manager kept all doors closed to reduce moisture evaporation from the footing.

Site 5's AH profile closely resembled Site 6's, with AH higher indoors than outdoors (figure 2B). There was a wetter period for the first day and half of the study period after which the indoor and outdoor AH were nearly matched, with up to 0.30 g/m^3 variation. The highest humidity was seen at Standard 1 near the arena center. Humidity readings at Standards 1 and 2 were not as uniform as T readings. Indoor humidity did decrease and responded rapidly with a decrease in outdoor AH. Figure 2C shows indoor RH values greater than outdoor RH.

Sites 1, 3, and 4 were more humid indoors than out, with differences ranging from 0.50 to 1.0 g/m^3 most of the time. Two of these arenas shared airspace with the horse stabling so had access to increased humidity from that environment. The trends in AH indoors did not track outdoor conditions as closely as in the arenas discussed previously.

At Site 1, the indoor arena and stable AH were similar most of the time, which would be expected since they shared a common airspace. Arena AH was 0.5 to 1.0 g/m^3 greater than outdoors most of the time with some peaks up to 2.0 g/m^3 higher. This footing had the highest percentage of organic material in the study and had the highest moisture content so there was potential for higher arena moisture level. Site 1 was watered in the late morning to early afternoon hours of 21 December. During this time, an inconsistent increase in indoor AH was seen across the indoor sensors. The wettest area, near Standard 1, was near the wall or "rail" of the arena, where the horses travel. This was done intentionally by the owner/manager to help reduce dust by applying more water to the heaviest traffic areas. Standard 1 sensor continued to record the highest AH for the rest of the study period. This sensor recorded some curious peaks in AH (1 g/m^3 increase over other indoor AH) that were not captured by either of the other two sensors. These early afternoon peaks were likely caused by horse traffic on the wetter footing material. The stable AH was higher than the indoor arena AH prior to the peaks in AH at Standard 1 so opening of large stable doors nearby could have contributed to increased humidity in the arena. The stable was about 8.4°C (15°F) warmer than outside overnight and prior to the moisture peaks in the arena. Conditions at Standard 1 were condensing most of the study period. RH in the arena was greater than outdoors during the study period.

Site 3 was very uniform in AH readings across the three monitoring locations with variation of 0.1 to 0.2 g/m^3 (Figure 1B). During night and morning hours the indoor AH appeared to track outdoor AH with a 0.3 to 0.5 g/m^3 variation. Times of greatest variation between indoor AH and outdoor AH would appear to coincide with shared airspace between the arena and stable. During afternoon hours, when riders would likely be present and stable-to-arena doors would be open, the stable AH and arena AH were within 0 to 0.3 g/m^3 (likewise temperatures in stable and arena were more similar, being within 0 to 2.2°C (0 to 4°F)). During night times, T variation was 5.6 to 8.4°C (10 to 15°F) between arena and stable. Otherwise, at night and mornings the difference between stable and arena AH was generally 1.3 to 1.5 g/m^3 . The indoor RH was

generally 5 to 35% higher in the arena than outdoors (figure 1C). Indoor and outdoor RH were virtually the same on the first study night but showed the most difference during daylight hours. Stable RH and arena RH were similar during times of presumed arena use and higher than outdoor RH.

As with temperature profiles at Site 4, indoor conditions tended only to track the largest outdoor trends. This is likely the consequence of having no deliberate ventilation openings in the structure during this cold weather period. This arena was the most humid of the three arenas that had low moisture content, inorganic footing materials. Indoor AH levels were 1.0 to 1.75 g/m³ above outdoors except during daily 11:00 to noon periods each of the three study days (coinciding with times when indoor and outdoor T were similar, which likely indicates that doors were opened for air exchange). Slight or subtle changes in outdoor AH were not mirrored by the indoor conditions. The highest humidity was consistently recorded at Standard 1 and the lowest humidity was recorded at the north wall. Indoor RH was 5 to 10% lower in the arena than outdoors since the indoor temperature was generally 4.5 to 8.4°C (8 to 15°F) warmer.

CONCLUSIONS

Temperature and humidity monitoring during cold weather within six indoor riding arenas has provided background information for a variety of indoor arena ventilation configurations and footing materials. Granted, there were too many variables in this uncontrolled field evaluation to make statistical observations (which was not the intent of the study), however trends can be observed based on the data collected.

Despite the label of “indoor” riding area, conditions within these well-managed facilities were almost the same as outdoor conditions and in some ways, even harsher. Indoor arenas have a reputation of being dusty but the data collected during this project confirmed the high humidities found in a previous study.

Increased moisture levels were seen in the arenas with stables attached when moist stable air had access to the arena environment.

Moisture from the large quantities of water used to dampen dust in the arena footing materials was thought to be the main contributor to the high indoor AH rather than horse activity alone. There is evidence that horse activity contributed to increased moisture at arena locations where horses were known to travel after the footing was watered. The two arenas that had moisture levels closest to outdoor conditions had no horse activity during the three-day study timeframe. Those two arenas also had more ventilation openings for fresh air exchange than three of the other four arenas.

Natural ventilation openings can allow interior conditions to be similar to outdoor. Ventilation opening ranged from nearly 0 (totally closed with infiltration the only air exchange) to 21.5 m²/100 m² (215 ft²/1000 ft²) arena floor area. Three of the six arenas had ventilation openings less than 0.5 m²/100 m² (5 ft²/1000 ft²) arena floor area. “Well ventilated” conditions, as determined by humidity and temperature levels, were observed in the unattached arena with openings of 1.4 m²/100 m² (14 ft²/1000 ft²) arena floor area.

The detached arena with the most ventilation openings of the six study arenas (21.5 m²/100 m² (215 ft²/1000 ft²)) had indoor T within 1.7 (3°F) of outdoor T, indoor AH within 0.25 g/m³ of outdoor AH, and RH was tracking the profile and lower than outdoor RH. All other arenas had higher indoor AH than outdoor AH. The attached arenas had higher AH, 0.5 to 1.5 g/m³

typically, than outdoors and RH was also 10 to 15% higher with a range of 5 to 25% higher than outdoors.

Ventilation and indoor environment evaluation needs more measurable criteria. Currently, good ventilation is commonly based on temperature and not humidity. In five of the six arenas studied, indoor temperatures compared favorably with “adequately ventilated” criteria, however, moisture levels appeared higher than necessary in some of those arenas. With the large open space within the arena it was easy to meet uniform T requirements, at least at the three sensor locations used in this study.

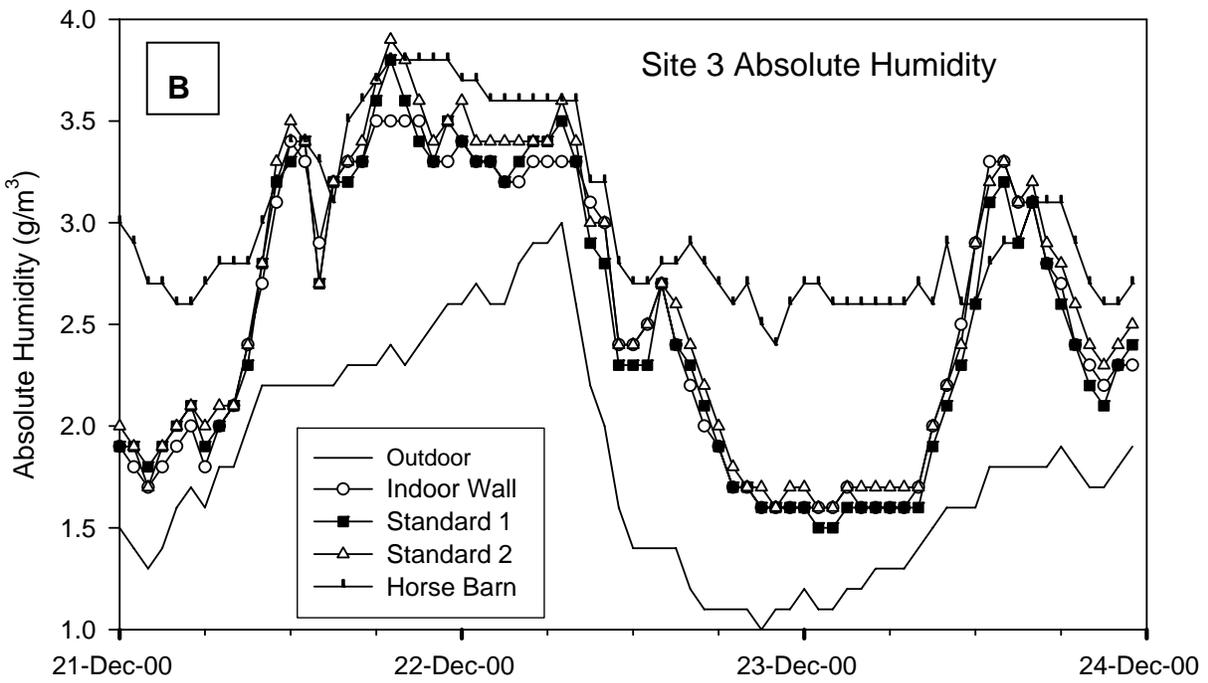
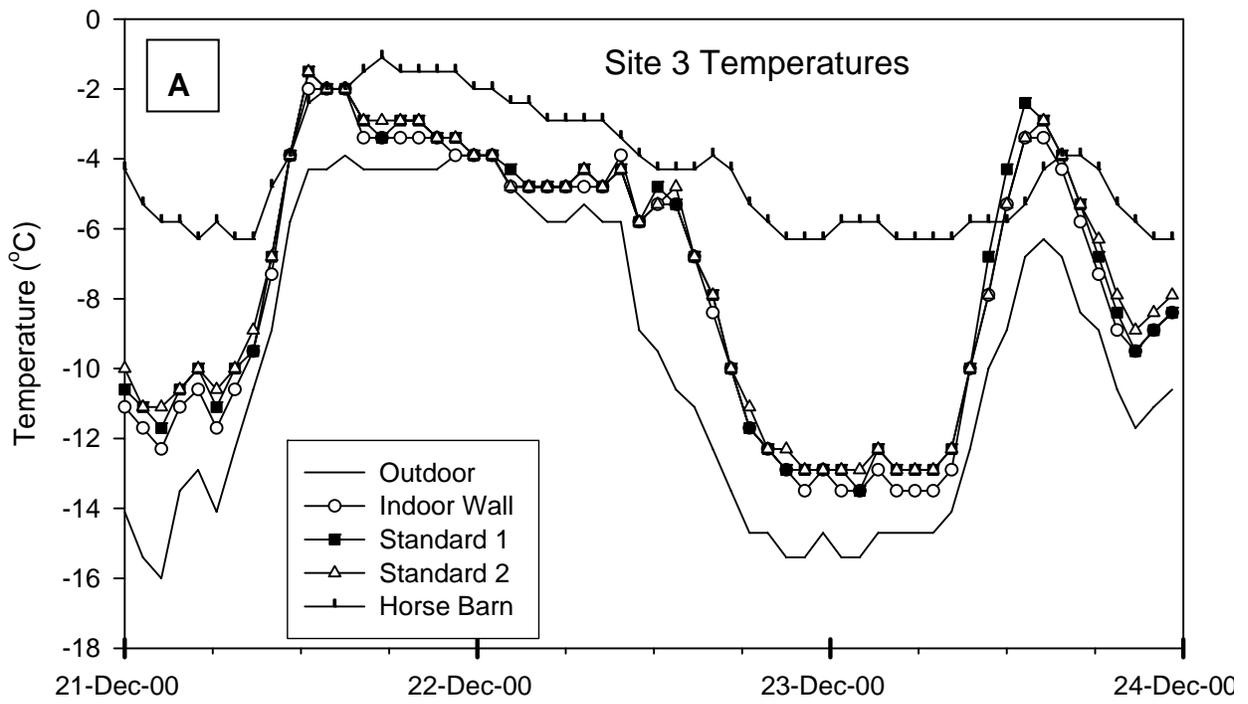
Acknowledgements

This research was supported in part by agricultural research funds administered by the Pennsylvania Department of Agriculture. The authors express much appreciation to the cooperating stable owners for assistance and continued interest in this project.

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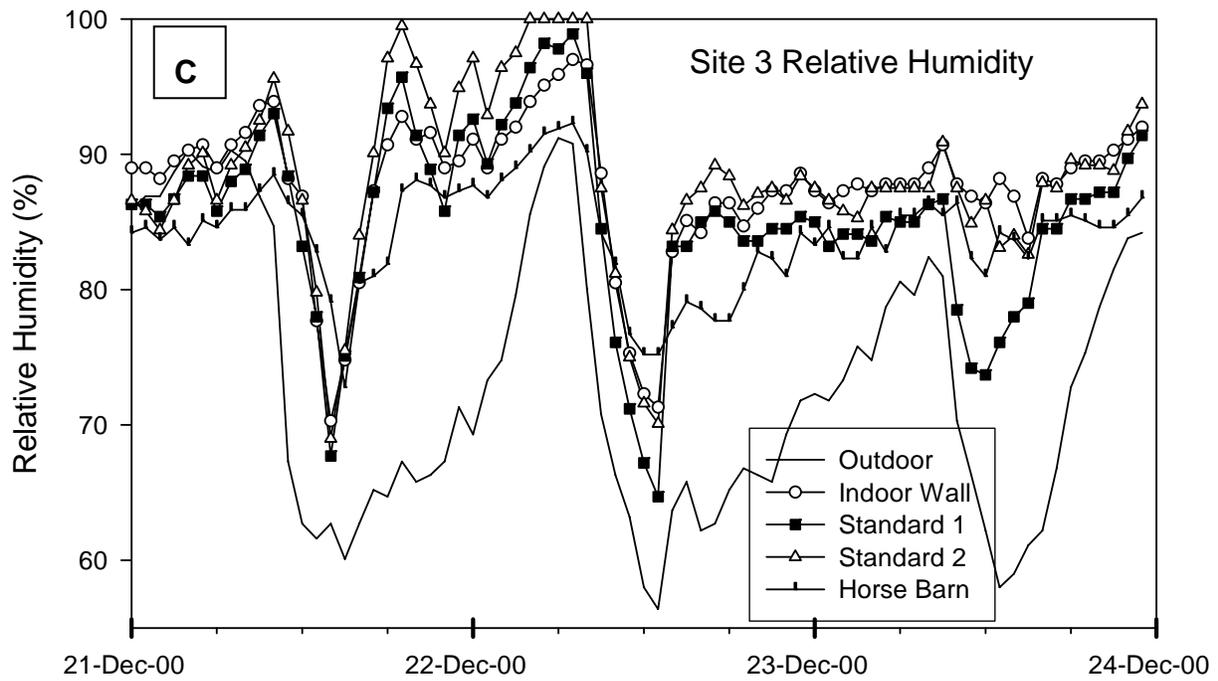
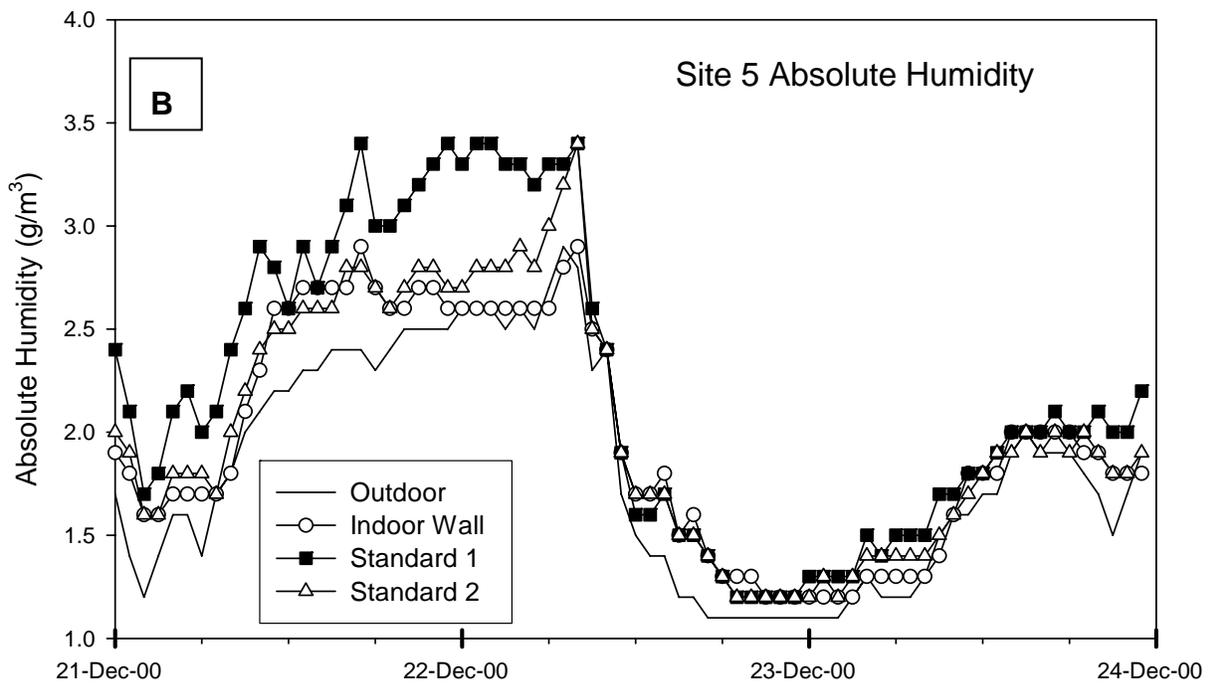
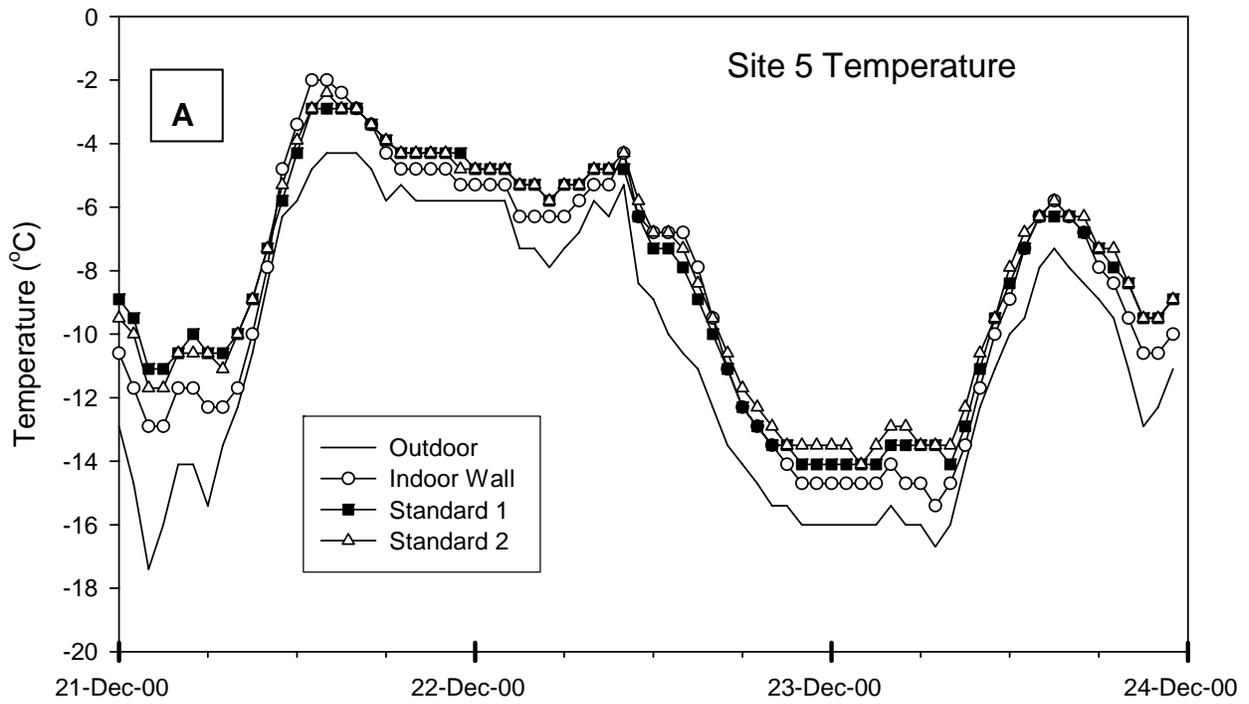


Figure 1. Temperature, absolute humidity, and relative humidity outdoors and at three arena locations in the eave and ridge ventilated Site 3 indoor riding arena. This arena was attached to the stable so the stable environment parameters also shown to demonstrate the effect of shared airspace with the indoor arena.



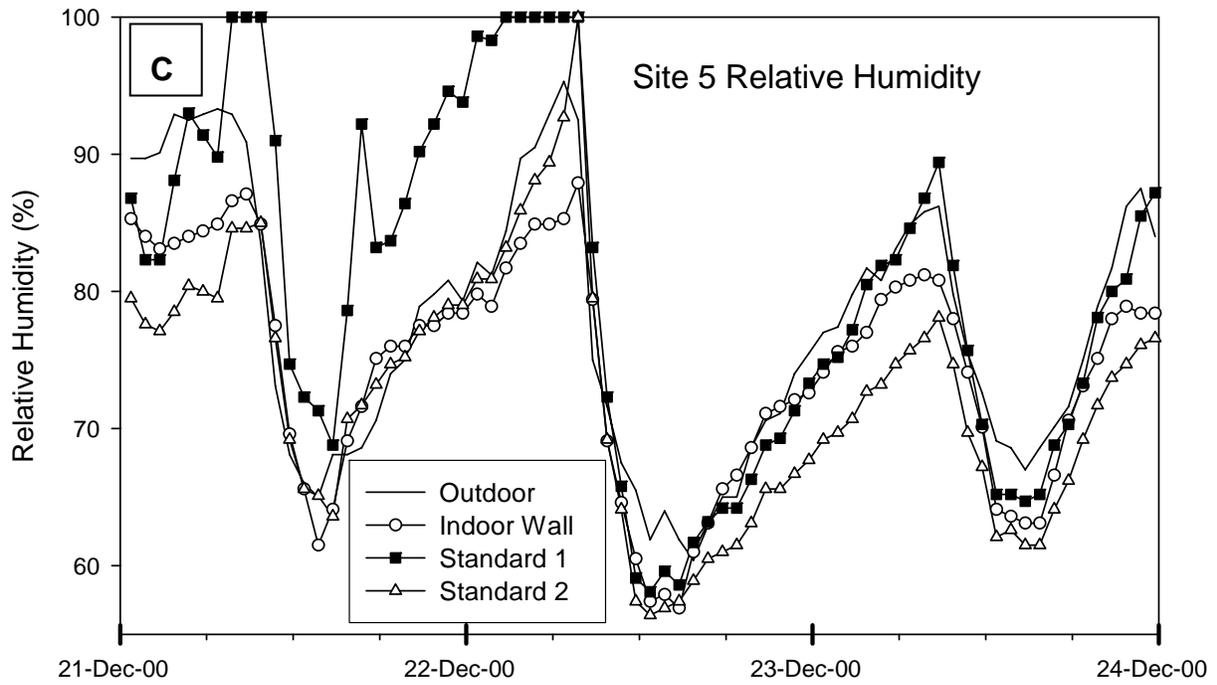


Figure 2. Temperature, absolute humidity and relative humidity outdoors and at three arena locations in the eave and cupola ventilated Site 5 indoor riding arena.

Academic citation for this conference paper:

Wheeler, E. F., J. L. Zajackowski, R. E. Graves. 2003. Temperature and humidity in indoor riding arenas during cold weather. ASAE Annual International Meeting. Las Vegas, NV, 8 pp. ASAE, St Joseph, MI.