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INFLUENCE OF WIND ON AIR MOVEMENT IN A FREE-STALL BARN DURING THE SUMMER PERIOD*

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Abstract

Use of natural ventilation in the barn should lead to optimal microclimatic conditions over the entire space. In the summer, especially during hot weather, higher air velocity cools cows, which helps to avoid heat stress. The paper presents the results of studies on the evolution of air movement in a modernized free-stall barn of the Fermbet type with the natural ventilation system during the summer period. Based on measurements of velocity and direction of air flow (inside and outside the barn) and observations of smoke indicator, the movement of air masses in different parts of the barn was identified. Significant variations of air flow at different levels of the barn were found. These differences deviate from the accepted patterns of natural ventilation, which can be found in the literature. The range of a draught and stagnant air along with the conditions in which they are built was determined. On this basis, recommendations regarding the location of barns on the plots and the improvement of ventilation in summer were made.

Key words: summer, wind, ventilation, dairy cows, free-stall barn

Dairy cow welfare and milk productivity are largely influenced by barn microclimate which depends on outside climate conditions. High production cows need significant amounts of fresh air (Albright and Timmons, 1984; Zähner et al., 2004). Insufficient amount of oxygen slows down metabolic processes, which in turn affects milk production. Inefficient ventilation systems in barns are quite often a cause of mammary gland infections or skin diseases (Cook et al., 2005). For example, Holstein-Friesian cows sweat out up to 30 litres of water to the air in the summer. High air humidity may decrease animal welfare and additionally such conditions are conducive to bacteria development. Moreover, insufficient air exchange ratio inside the barn results in the increased concentration of noxious gases produced as a result of animal waste decomposition.

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Natural ventilation systems inside barns should be designed in such a way as to obtain optimal microclimatic conditions throughout the entire area and at the level which would not be harmful to animals. Natural ventilation is the most popular ventilation system used in free-stall barns. Air movement is mainly driven by thermal displacement, wind and difference between the level of inlet and outlet openings (Reppo et al., 2004).

According to Romaniuk et al. (2005), air flow velocity inside a barn should remain within the range 0.2–0.5 $m \cdot s^{-1}$ depending on season of the year. When air velocity inside a building exceeds recommended values, cows may suffer from overcooling, which influences animal welfare and milk production levels. However in the summer season, especially during heat waves, increased air velocity and cooling play a positive role because they reduce the risk of thermal stress (Armstrong, 1994; Lautner and Miller, 2003).

Material and methods

The aim of the paper is to define the influence of wind energy and direction on air movement inside a free-stall barn in the course of two summer months. Based on measurements of air velocity and direction inside and outside the building as well as observations of smoke produced by smoke generators, the authors have determined air flow directions in particular sections of the cow barn. It was also possible to mark out areas where air stood still or where draughts occurred.

Research object

Measurements of air velocity and direction were conducted inside a cow barn (Fermbet construction system) adapted as a free-stall barn for 176 cows. The building of 1580 m^2 usable floor area is located in the village of Kobylany, the Małopolska region. It is oriented along the east-west axis. From the south, the building is extended with some additional social rooms for employees and milking parlour with the holding area. It is a typical building constructed from pre-fabricated reinforced concrete with a double-pitched roof (gradient 45%). The building is equipped with a natural gravitational ventilation system with an adjustable curtain wall on longitudinal walls and outlet openings in the form of ridge vents.

Measurement methods and the distribution of measurement points

To carry out the measurements, 18 measurement points were identified across the barn area, 6 in each of the manure alleys (alley I, alley II, and alley III) (Fig. 1). Instantaneous measurements of air flow velocity were conducted in selected points at the level of 1 meter above the floor. This was done with the help of Windmaster 2 anemometers. Moreover, relative instantaneous humidity and air temperature were measured with a thermo hygrometer HD 8901 provided by Delta OHM. At the same time, weather conditions outside the building were recorded (wind velocity and direction, temperature and relative air humidity). The measurements were made daily throughout June and July 2010, at 11 am and 2 pm.

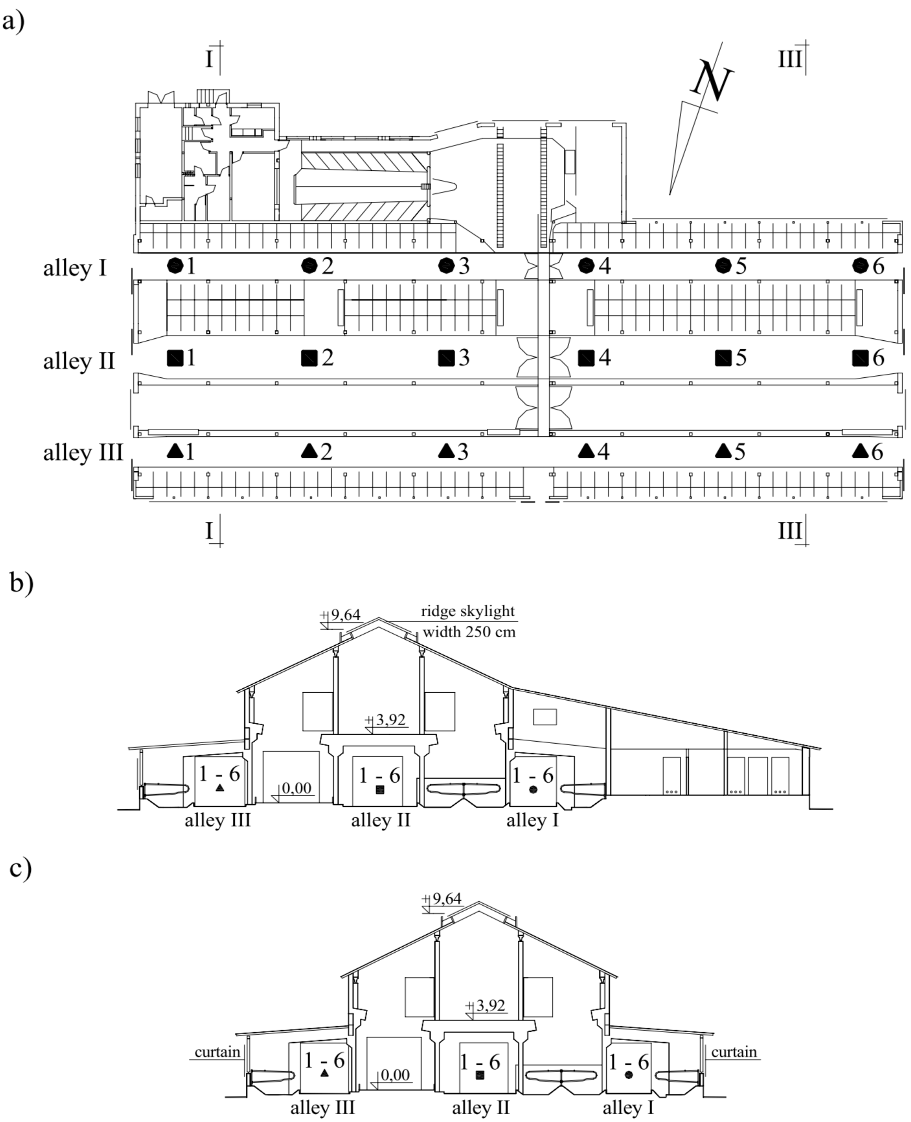

Fig. 1. Distribution of measurement points for wind velocity, temperature and relative air humidity (1–6) in the Kobylany barn
a – projection, b – cross-section I–I, c – cross-section III–III

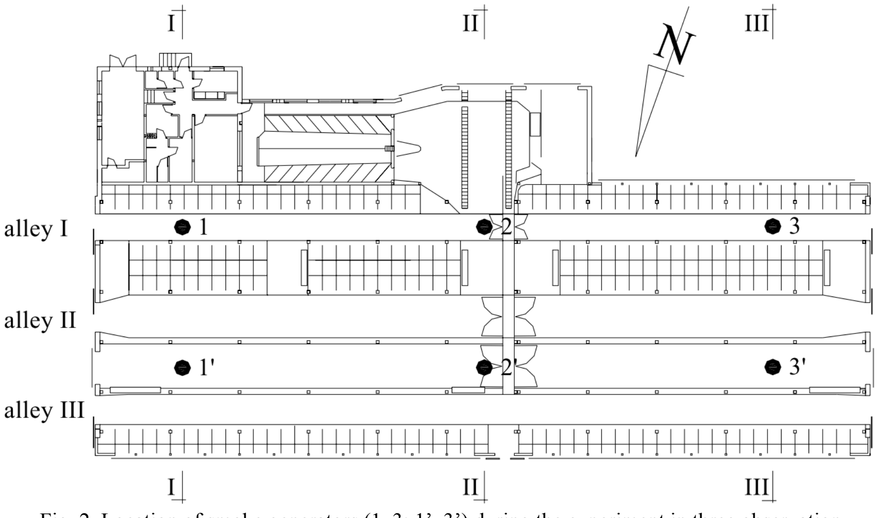

Fig. 2. Location of smoke generators (1–3; 1'–3') during the experiment in three observation cross-sections I–I, II–II, III–III

Observations of air flow in the barn were possible thanks to the use of smoke from smoke generators. The movement of that smoke was photographed and recorded. Smoke generators were positioned in three significant observation cross-sections (Fig. 2). During the measurements and observations of air movement, curtains in the longitudinal walls were completely deserted and all the gates were opened.

Results

The analysis of air velocity measurements in the selected points was carried out by calculating average values of all results obtained, separately for winds blowing perpendicularly and parallel to longitudinal building axis. In June and July 2010, wind velocity was between 1 and 2.5 $m \cdot s^{-1}$. Outside air temperature remained in the range 20.3–25.9°C, with relative humidity of 70–73%. Indoor air temperature was at the level between 21.4 and 24.4°C, and relative humidity did not exceed 70%.

When the wind blew perpendicularly to longitudinal walls of the building, air movement velocity in the manure alley I, where the lying areas are directly adjacent to the wall, was lower than the value recommended for the summer season. Moreover, the recommended air flow velocity ($V_{opt} = 0.5$ $m \cdot s^{-1}$) was significantly exceeded in measurement points at all manure alleys at the western wall. A similar situation occurred in the lying area in the eastern side of the barn, in alley 2, where air movement velocity at the points 1 and 2 equalled on average 1 $m \cdot s^{-1}$ and 0.6 $m \cdot s^{-1}$ respectively (Fig. 3). Optimum air flow velocities for dairy cattle were observed in the central part of the barn (measurement points 3 and 4), around double boxes between manure alleys no. 1 and 2.

The measurement results obtained were confirmed by observations of smoke movement in particular sections of the barn (Fig. 4).

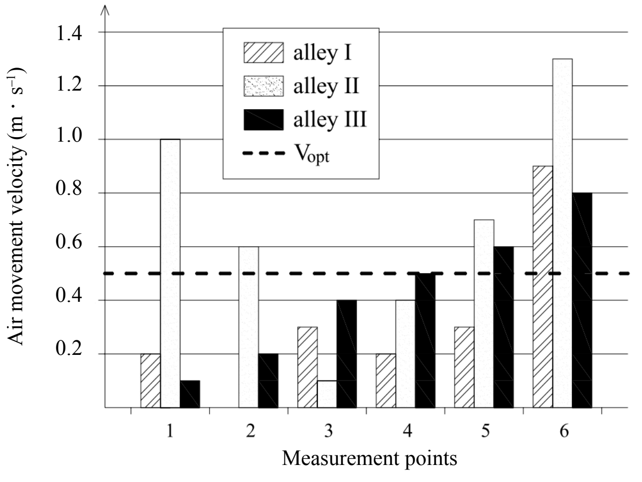

Fig. 3. Average air movement velocities measured in June and July 2010 at 11 am and 2 pm in scraper alleys when winds blew perpendicularly to the barn wall

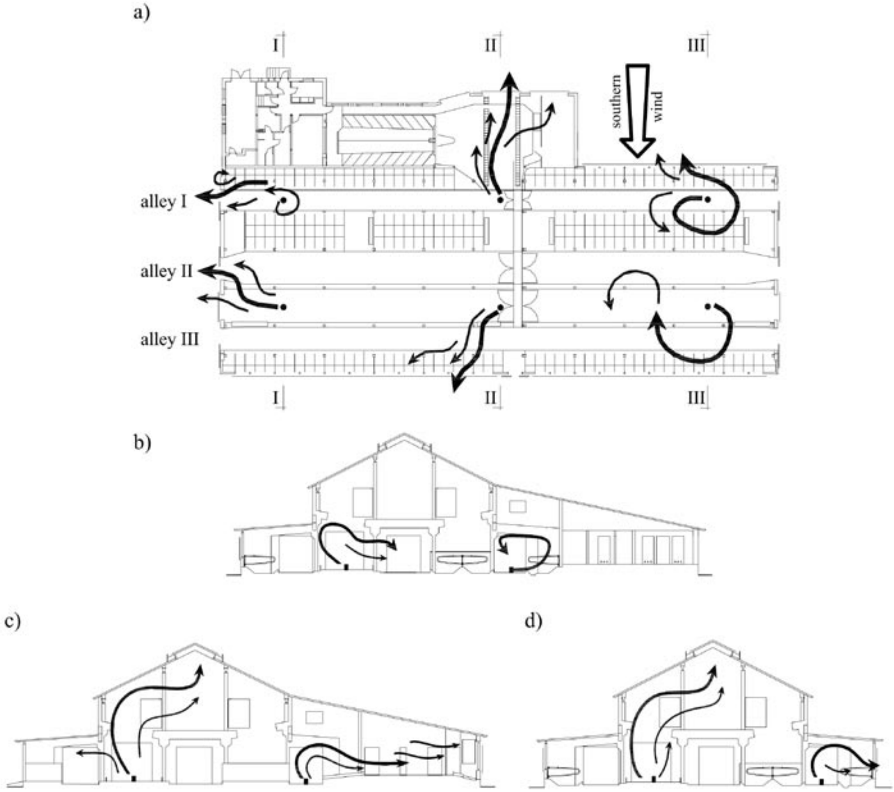

Fig. 4. Smoke movement during the experiment with smoke generators in the barn on 30 June 2011 at 12 am; air temperature equalled 25.9ºC, southern wind (perpendicular to the barn):
a – horizontal projection, b – cross-section I–I, c – cross-section II–II, d – cross-section III–III

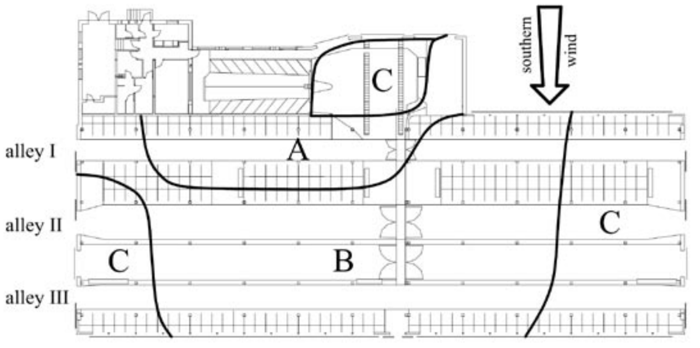

Fig. 5. An overview of the cow barn with the three zones: A – standstills, B – optimal air velocities, C – draughts; observed when wind blew perpendicularly to the building

Based on measurements and observations of air movement, the authors have divided the building into zones with different air velocity. Most convenient conditions were observed in the central part of the barn (zone B). Taking into consideration the temperature in the barn on that day (23.2°C), we can say that the zone C and the draughts that occurred in this zone (velocity 0.5–1.4 $m \cdot s^{-1}$) protected the animals from overheating. The zone A, nearby the milking parlour and adjacent areas (Fig. 5), was characterized by standstills.

In the case of western wind blowing parallel to the building axis, air movement velocity in windward manure alleys decreased gradually. The highest velocity (1 $m \cdot s^{-1}$) was recorded along longitudinal walls in the western part of the barn and around the gate leading to the feeding alley. In this part of the barn, the cows were most severely exposed to draughts, and the fresh air entered mainly through the open gate. In the central part of the barn, air velocity remained at the level which could be considered as unsatisfactory. The lowest velocities were recorded in this part of the scraper alley where the lying area is connected to the extension room and in the northern part, mostly along the longitudinal wall (Fig. 6).

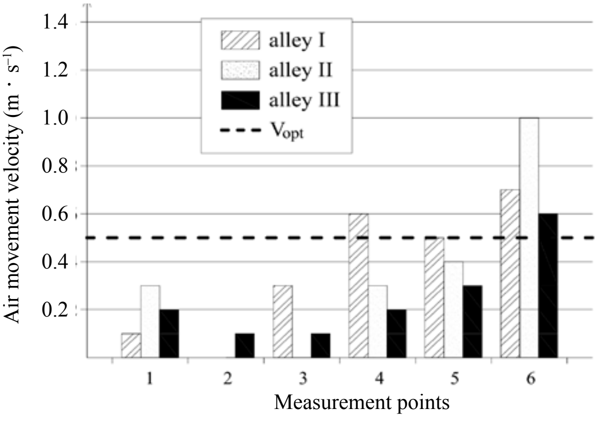

Fig. 6. Average air movement velocities measured in June and July 2010 at 11 am and 2 pm in scraper alleys when winds blew parallel to the barn wall

Smoke movement observations were also carried out for wind blowing parallel to the barn. In the case of west-east winds (parallel), the air mainly entered the building through the open gate in gable walls of the barn. Openings in longitudinal walls served rather as air outlet openings (Fig. 7). The eastern part of the barn suffered from poorest ventilation (cross-section I–I). The air entered the barn through inlet openings in longitudinal walls with lowered curtain walls and left the building through the open gate in the eastern part. In the central part of the barn (cross-section II–II), smoke movement during the experiment was disturbed the most. Contrary to the situation in the eastern part of the barn, the air left the building through outlet ridge vents only in the central part of the barn. In the western part of the barn, the movement of air was disturbed by the open gate, which resulted in draughts.

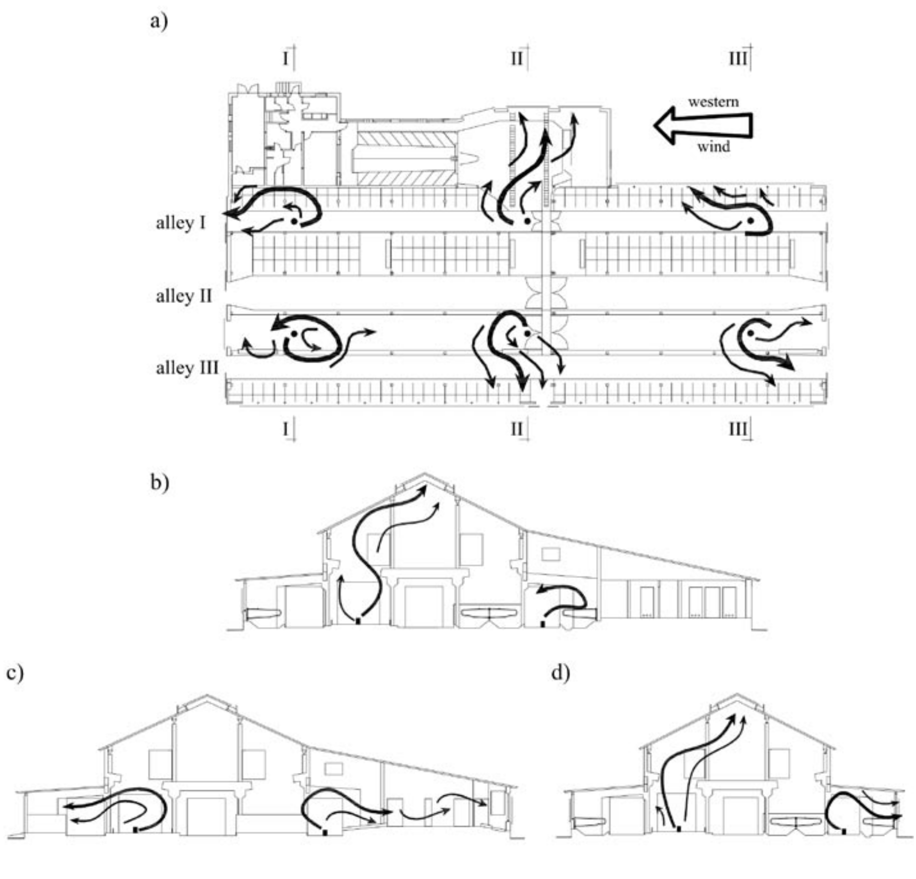

Fig. 7. Smoke movement during the experiment with smoke generators in the barn on 9 July 2011 at 12 am; air temperature equalled 19.9°C, western wind (parallel to the barn):
a – horizontal projection, b – cross-section I–I, c – cross-section II–II, d – cross-section III–III

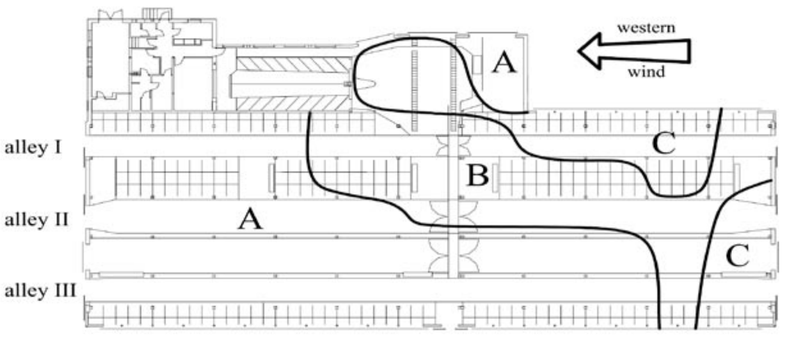

Fig. 8. A projection of the cow barn with the three zones: A – standstills, B – optimal air velocities, C – draughts; observed when wind blew perpendicularly to the building

The air was distributed the best way in the lying area with double boxes between alleys 1 and 2 in the western part of the barn and the perpendicular alley leading to the holding area. In the central and eastern part of the barn, air movement was not satisfactory and air velocity was near 0.0 $m \cdot s^{-1}$ (Fig. 8).

Discussion

Cattle are able to adapt well to changeable temperature conditions, particularly if they are bred in free-stall barns. The temperatures between –10 to 20°C do not exert much influence on milk production when relative air humidity remains at the level of 50–70% (Lautner and Miller, 2003; Romaniuk at al., 2005; Jaśkowski et al., 2005).

Animals experience heat stress when the temperature in the barn increases above 20°C and when air humidity is at an unsatisfactory level. The cows begin to move slowly, they eat less and breathe out heavily to get rid of the heat. If the temperature rises from 20°C to 30°C, a cow eats approximately 1.5 kg less fodder and produces 3 to 5 litres of milk less. As a result, the animal's physiological parameters go down (Spiers et al., 2004).

Air flow velocity in barns should not exceed 0.2 $m \cdot s^{-1}$ during the winter, and 0.5 $m \cdot s^{-1}$ during the summer if the heat exchange ratio remains within the range of 350 to 400 $m^3 \cdot animal^{-1} \cdot h^{-1}$ (Solan and Jóźwik, 2009). Draughts are not a positive phenomenon because they result in sudden cooling of the body, which leads to increased vulnerability to diseases. However in special cases, this principle may not be followed. In such situations, air movement velocity is increased in order to lower the temperature inside the barn, especially during hot days. According to Wathes et al. (1983), summer winds of 6–7 $m \cdot s^{-1}$ are not detrimental to cow welfare, and the cooling effect is already observed at 1–2.5 $m \cdot s^{-1}$. The challenges appear when high inside air temperatures are accompanied by complete air standstill. In such conditions, cow fertility may be negatively influenced (Ray et al., 1992). Standstills in the investigated barn mainly depended on wind direction. It could be assumed that wide barns with large manure and feeding alleys will be more easy to ventilate. The investigated barn contradicted these assumptions.

Proper air flow directions inside a free-stall barn in the summer period should develop as in Figure 9 (Chastain, 2000). However, this is a purely theoretical scheme as it assumes that the wind will blow perpendicularly to the barn. In fact, the influence of wind on air movement inside building and gravitational ventilation efficiency depends on local conditions, such as relief configuration, surrounding buildings and how the building is located. Also, the building itself and the positioning of milking parlour, holding area and other rooms influence the way air is distributed at different areas of the building (Herbut, 2010). In the investigated barn this type of air movement configuration (Fig. 9) was observed in some parts of the building and changed depending on the dominating wind direction. Scarce literature on cattle breeding, cattle welfare, barn ventilation and building construction takes into consideration the influence of weather conditions on air movement in barns (Brouk et al., 2001; Teye et al., 2008). In the case of free-stall barns this factor is very important.

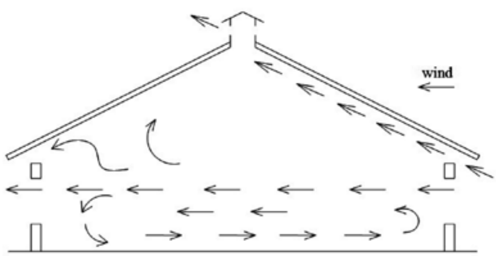

Fig. 9. Proper air movement directions in the summer with open side curtains and wind blowing perpendicularly to the building (Chastain, 2000)

In the case of free-stall barns with natural ventilation, the power and direction of wind largely influences the performance of ventilation systems. When the gates situated in gable walls were open, the situation inside the investigated barn was very unfavourable, because the air moved uncontrollably in both gable zones. The air entering the building through openings in curtain walls was blown out through these gates instead of moving in accordance with the diagram in Fig. 9. Optimal conditions of air movement, which were created in the central part of the barn when the wind blew perpendicularly to the walls, confirm recommendations that can be found in many other works (Romaniuk et al., 2005). They define most favourable conditions of air exchange in free-stall barns when inlet openings are located opposite each other and perpendicularly to most common wind directions.

It could be also agreed at this point that Palmer's recommendations (2005) are correct. He suggests that it is necessary to position barns in such a way that their longitudinal axis runs north-south, which would improve the performance of natural ventilation supported by wind velocity. Unfortunately, in the investigated barn longitudinal axis of the east-west direction was not consistent with the directions of predominant winds. That is confirmed by Lorenz (2005), who says that Poland is dominated by western winds, which are the strongest in winter period. Results of wind velocity and directions obtained in the course of this research in Kobylany were in line with velocity values and wind directions determined by multiannual studies carried out in the nearest meteorological station in Balice (Ośródka et al., 2010). According to this study, wind velocity in the area ranges between 0 and 3.5 $m \cdot s^{-1}$ and western winds are most frequent. In Kobylany, the average velocity was 0–2.5 $m \cdot s^{-1}$, which was probably caused by local winds, relief configuration and the existing building development, which most significantly influence air movement inside the barn.

It would be possible to improve air movement conditions in the eastern part of the barn by installing devices supporting natural ventilation, for example mixing fans hung at the ceiling. The application of these solutions would improve air quality in the barn in the summer season and also improve cow welfare and their productivity.

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Wpływ wiatru na ruch powietrza w oborze wolnostanowiskowej w okresie letnim

STRESZCZENIE

Użytkowanie wentylacji naturalnej w oborze sprowadza się do osiągnięcia optymalnych warunków mikroklimatycznych na całej przestrzeni użytkowej hali. W lecie, zwłaszcza podczas upałów większa prędkość ruchu powietrza ochładza krowy i umożliwia uniknięcie zjawiska stresu cieplnego.

W pracy przedstawiono wyniki badań nad kształtowaniem się ruchu powietrza w zmodernizowanej oborze wolnostanowiskowej typu „Fermbet” z systemem wentylacji naturalnej podczas lata. Na podstawie pomiarów prędkości i kierunku ruchu powietrza wewnątrz i na zewnątrz obory oraz obserwacji dymów wskaźnikowych dokonano rozpoznania przemieszczania się mas powietrza w poszczególnych jej częściach.

Stwierdzono duże zróżnicowanie kształtowania się ruchu powietrza w różnych płaszczyznach obory odbiegające od przyjmowanych literaturowo schematów wentylacji naturalnej. Wyznaczono strefy występowania przeciągów, zastoisk powietrza oraz warunków podczas których powstały. Na tej podstawie sformułowano zalecenia dotyczące sytuowania obór na działkach oraz poprawy działania wentylacji w lecie.