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SPATIAL DISTRIBUTIONS OF AIRBORNE DUST IN A COWS BARN EXPOSED TO INFLUENCE OF DIFFERENT VENTILATION RATES

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Abstract: Information on the concentration of dust particles is an important microclimate parameter that characterizes the local environmental quality of each livestock building. Increased concentration of dust particles primarily affects the indoor air quality and, consequently, the animal and workers health. Among many others, ventilation rate is a vital parameter that controls the spatial distribution of airborne dust particles in livestock buildings. This was the main motive for authors of this paper to research the influence of rotation rate of under-roof axial fans (i.e. the air flow rate) on airborne dust particles distribution crossover the barn specified for tied cows breeding. During a series of performed experiments, six different air flow rates have been maintained in the range between 0 $m^3 \cdot h^{-1}$ and 48000 $m^3 \cdot h^{-1}$. Flow rate has been controlled by special electronic control unit, which provided six different rotation rates of two under-roof fans, including the neutral regime (natural ventilation only). Measurements have been performed at four typical height levels (0,5 m; 1,0 m; 1,5 m and 2,0 m), cross-over the three lateral and four longitudinal characteristic building sections. Consequently, 48 measuring points were appropriately selected, in order to cover the indoor space in adequate way. Comparative analysis of air flow velocities and dust concentrations showed that this fan setup may give satisfactory results under adequate operational regime. Certain working regimes were recommended for use, and the third rotation rate step, generating the airflow of 37300 $m^3 \cdot h^{-1}$ or indoor air exchange level of approximately 25 h^{-1}, has been found as the most suitable.

Key words: fan flow rate, airflow velocity, airborne dust, livestock buildings.

Introduction

The term “airborne dust” commonly represents solid particles having a diameter up to 100 μm, which are suspended in the air. Within the total (inhalable) dust content, fraction of respirable dust should be distinguished and analysed separately, because it contains very small particles characterized by diameters less than 5 μm (*Jacobson, 2007*). Dust particles of this kind are of special engineers interest because of their capability of deep penetration in the lungs. In opposite, larger particles are less dangerous because most of them are retained in the upper parts of the respiratory tract. The origin of dust in livestock buildings is primarily organic. It is most commonly produced from the animal body surface (dried skin particles), bedding, dried feces and concentrated feeds (*Wang et al*., *2000*).

It has been recognized worldwide that an increased level of airborne dust concentrations may cause a variety of different health problems of breeding animals and working people. Consequently, the animal's and employee's productivity could be seriously decreased. However, recommendations for allowable concentrations of dust are given with respect to the human sensitivity. Nowadays, the most commonly accepted value of allowed concentration is 10 $mg \cdot m^{-3}$ for total and 5 $mg \cdot m^{-3}$ for respirable dust. In order to prevent the occurrence of long-term health problems, much more stringent limit has been recommended in the past: only 2.5 $mg \cdot m^{-3}$ for total and 0.2 $mg \cdot m^{-3}$ for respirable dust (*Jacobson et al.*, *2008*).

So far, a wide variety of research attempts related to enriching and verification of the available data bases and/or modeling the governing parameters of various production processes in animal husbandry have been made (see *Pearson and Sharples 1995*, *Petrović and Topisirović 1997*, *Petrović et al. 1998*, *Takai et al. 1998, Petrović et al. 1999, Jacobson et al. 2008, Topisirović and Djurić, 2008, Bartzanas et al. 2010*, among many others). Following this practice, this study analyzes the influence of multi regime roof fans flow rate on the concentration of particular airborne dust fractions. On the base of performed experiments, recommendations on fan usage and settings are given.

Material and Methods

In this study are presented experimental results of researching the effect of De Laval ventilation system Multifan with control unit STD (Manual 8 A thermostatic controller T15 - WD and DF 1300 fans) on the spatial distribution of airborne dust particles concentration.

This system can operate at six different rotation rate regimes. Three axial fans of indoor type, are located below the roof, but above the feeding alley. Maximum fan capacity is 48000 $m^3 \cdot h^{-1}$, at negligible pressure difference and the maximum rotation speed of 400 rpm. Measurements in the experimental cows barn are carried out at 48 measurement points (Fig. 1). These points were arranged in three lateral sections, with 4 vertical rows in each section, and the four height levels (0,5 m; 1,0 m; 1,5 m and 2,0 m). Lateral measuring sections were placed in 3 distinctive parts, as it is presented in Fig.1. The first section was set at 3.30 m from the front door to the feeding alley on the north side, while the other two lateral sections were placed in a way to provide the distance of 14.90 m between any of two subsequent sections. This way, the fans influence zones are covered. Vertical arrays are placed symmetrically above the feeding places and manure channels (*Curtis et al., 1996*). Height levels are at 50, 100, 150 and 200 cm, with the same goal as in the previous case. Concentrations of dust fraction ≤ 3 μm and ≤ 5 μm have been measured under carefully controlled indoor conditions. The measurements have been performed for five different fan operating regimes and neutral regime (natural ventilation).

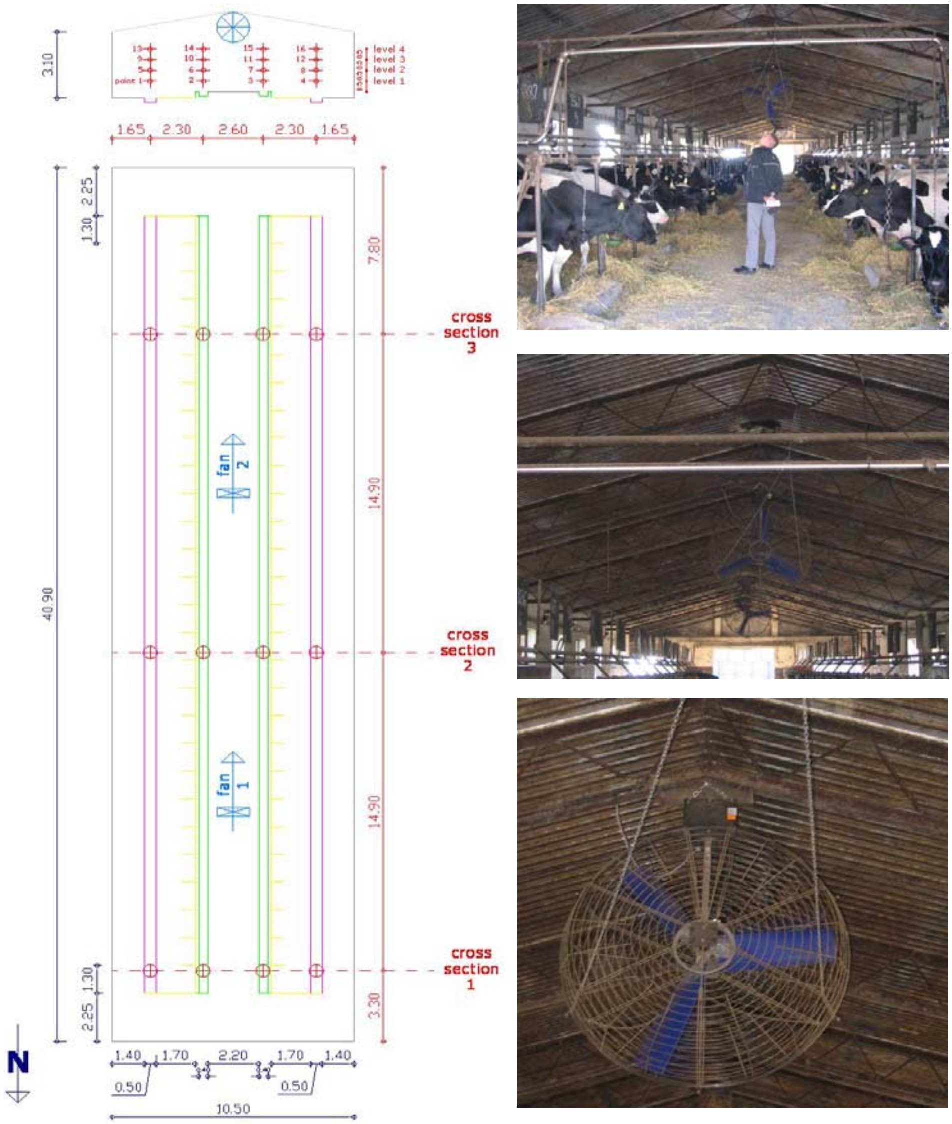

Figure 1. Building layout and measuring points setup (left) and photos of indoor ambient (right)

Results and discussion

During the first measurement series of dust concentration fans were switched off. In those conditions, concentrations of dust particles in different parts of the experimental cow barn depend on natural ventilation, i.e. on the natural air flow and air humidity. Consequently, concentrations of dust fraction of up to 5 µm were higher compared to corresponding concentrations when roof fans were in any operating regime (Figures 2a to 5a, respectively).

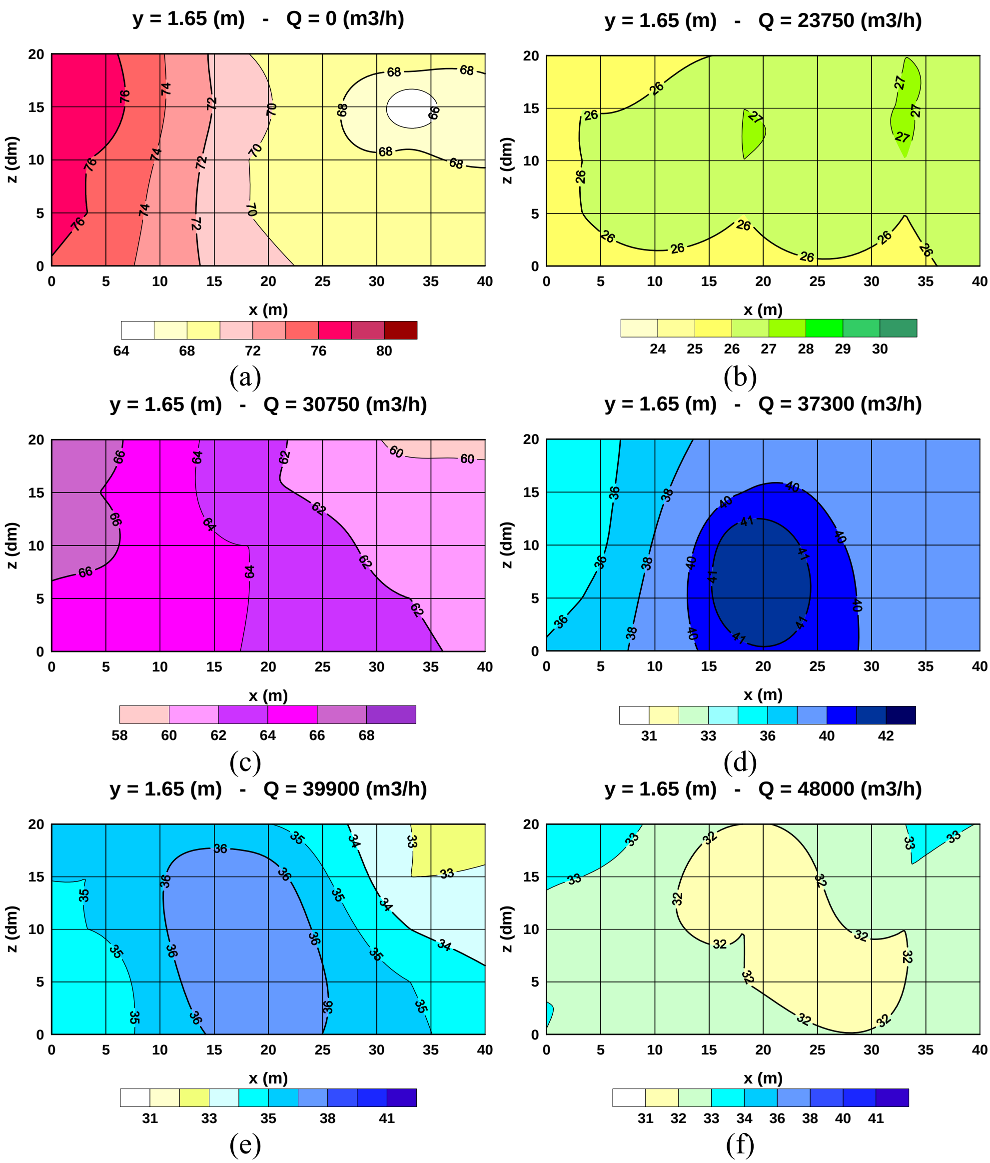

Figure 2. Distributions of 5 µm dust fraction concentrations along the first longitudinal cross section at 3,95 m from the eastern wall of the barn, under different operating regimes of roof fans

Concentrations were fairly uniform over the object volume, which confirms stationary state of air velocity fields during the absence of forced ventilation. Some deviations of the dust concentration field from this rule, that were rarely recorded, are caused by cows activity, different bedding composition, distribution of concentrated feeds etc.

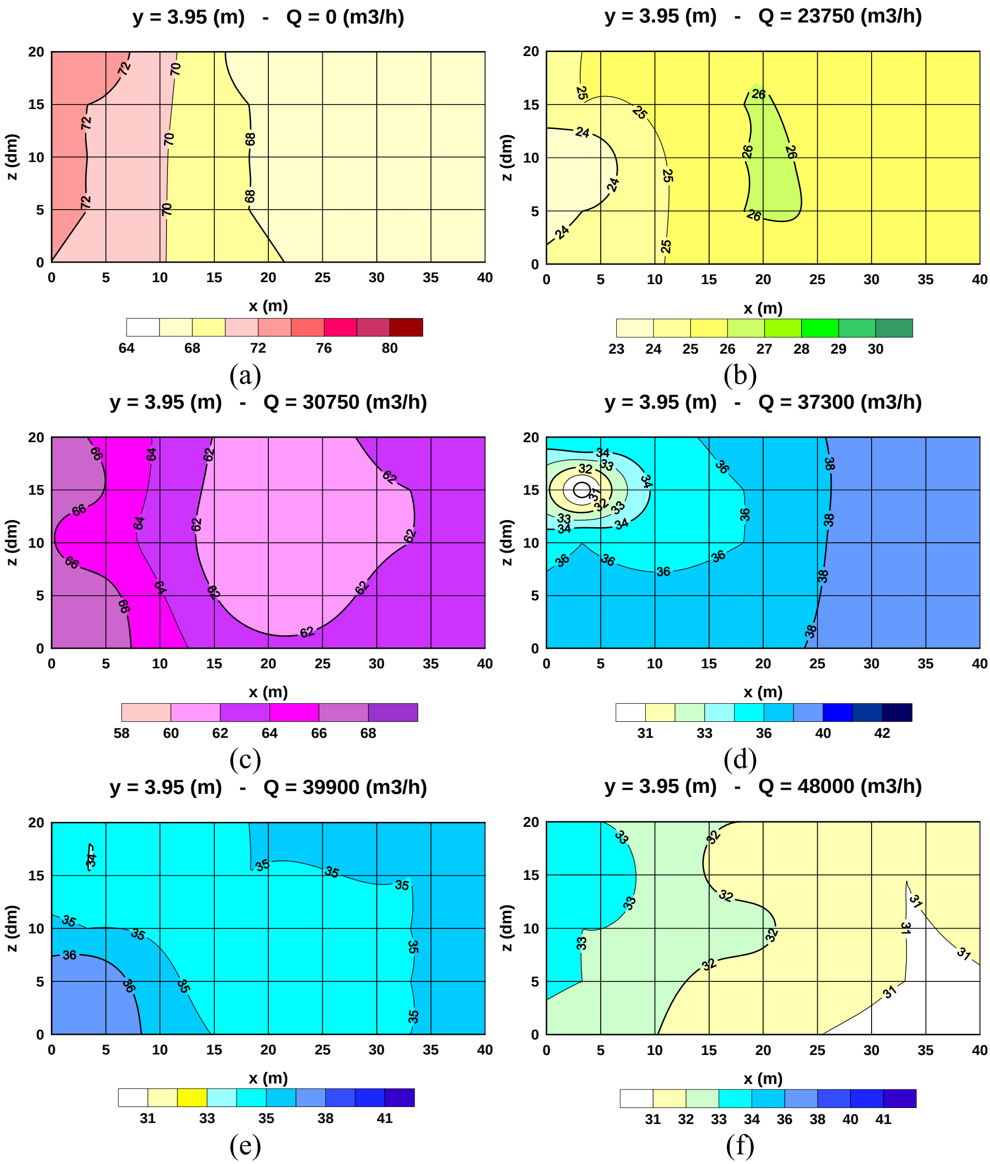

Figure 3. Distribution of 5 µm dust fraction concentrations along the second longitudinal cross section, at 3,95 m from the eastern wall of the barn, under different operating regimes of roof fans

The second series of measurements was performed under the controlled fans nominal air flow of 23750 $m^3 \cdot h^{-1}$. This operation regime resulted in the lowest airborne dust concentration, with respect to all other operating regimes (Figures 2b to 5b, respectively). In this mode, fans provide adequate air exchange, and acceptable air flow velocity, that does not re-suspend dust sediment from the floor and other surfaces.

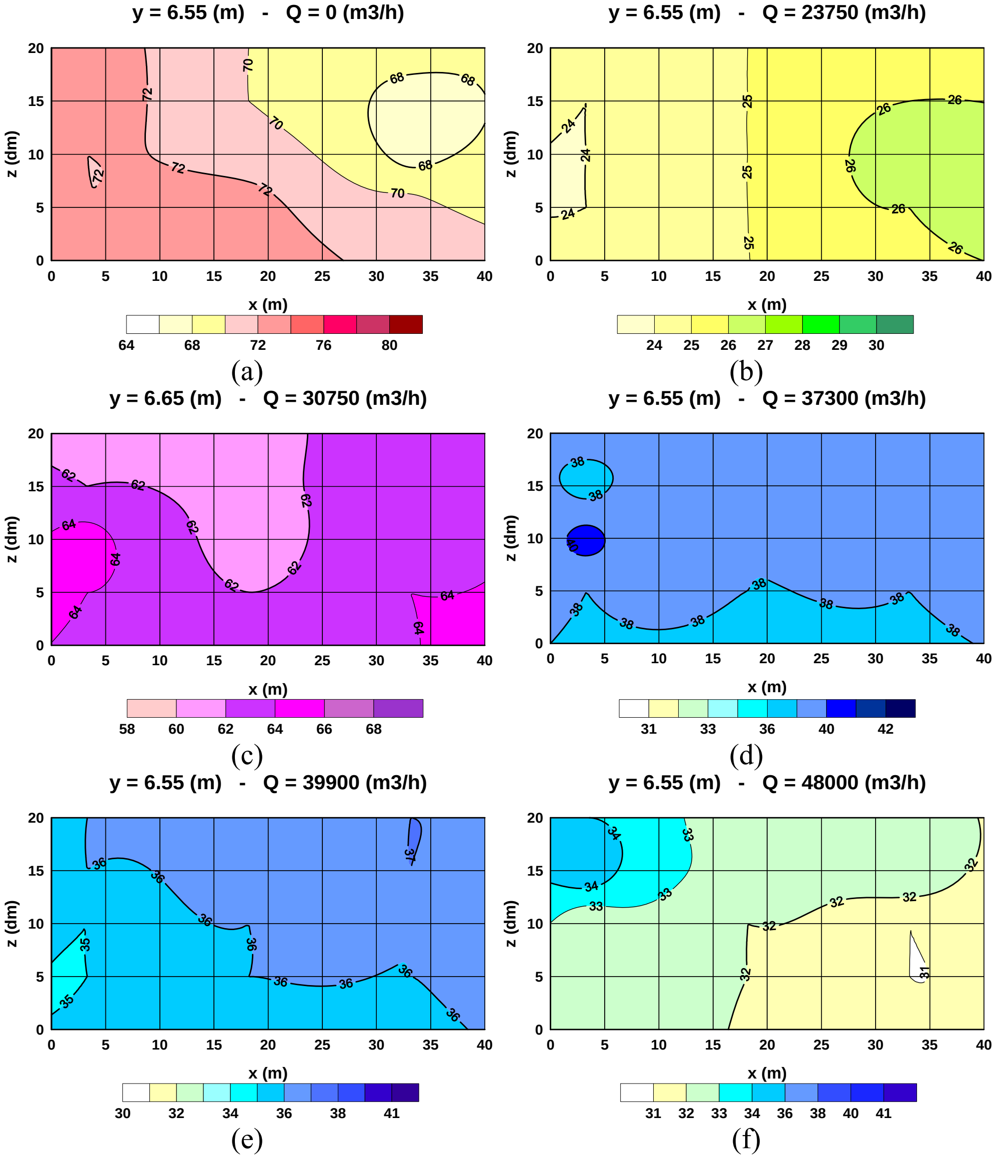

Figure 4. Distribution of 5 μm dust fraction concentrations along the third longitudinal cross section, at 6,55 m from the eastern wall of the barn, under different operating regimes of roof fans

All those issues resulted in reduced airborne dust concentrations in the stable, compared to other fans operating regimes - the average concentration of dust fraction with ≤ 5 µm in diameter decreased from 72 particles·ml^{-1} (natural ventilation, Q = 0 m^3·h^{-1} - Fig. 3a) to only 26 particles·ml^{-1} (forced ventilation, Q = 23750 m^3·h^{-1} - Fig. 3b), i.e. by 64%.

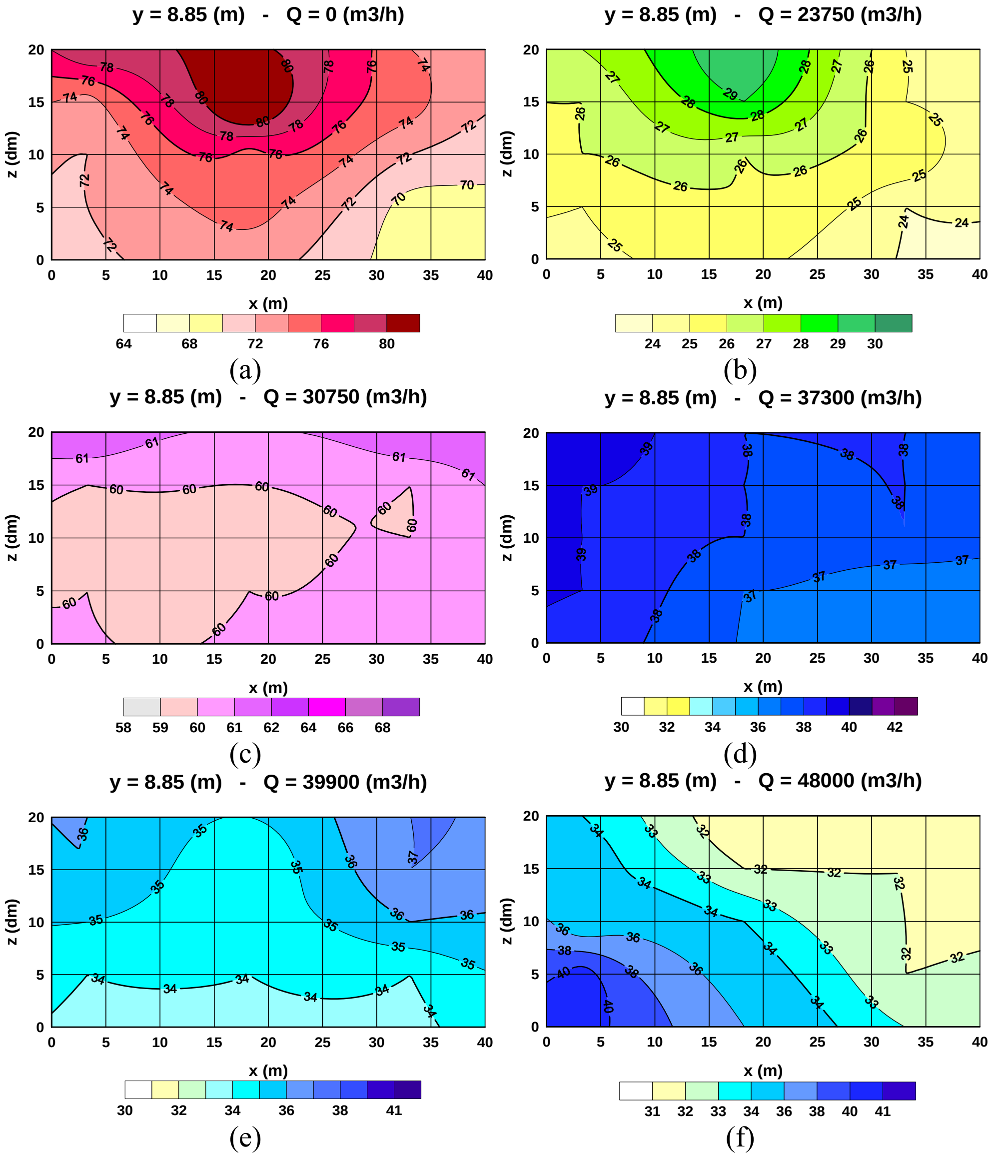

Figure 5. Distribution of 5 µm dust fraction concentrations along the fourth longitudinal cross section, at 8,85 m from the eastern wall of the barn, under different operating regimes of roof fans

The third series of measurements comprehended 2nd fan operating regime with nominal air flow rate of 30750 $m^3 \cdot h^{-1}$. The highest concentrations of dust particles in the experimental facility were recorded (Figures 2c to 5c, respectively) in this regime, compared to all the other regimes (excluding switched of fans). It can be expected that dust concentration would additionally decrease after a longer fan operation.

During the fourth (Figures 2d to 5d, respectively) *and fifth* (Figures 2e to 7e, respectively) *series of measurements*, that included 3rd and 4th fan operating regime (respectively) with nominal flow rates of 37300 $m^3 \cdot h^{-1}$ and 39900 $m^3 \cdot h^{-1}$ (respectively), reduction of concentrations of both dust fractions were observed. Fairly uniform dust concentration distributions were established in the barn. In these operating regimes, convective transport (exhaust) of dust particles exceeds its introduction into air flow as a result of settled particles raising from the floor and other surfaces within the facility.

The last, sixth series of measurements included 5th fan operating regime with maximum air flow of 48000 $m^3 \cdot h^{-1}$. The concentrations of airborne dust particles began to rise again (Figures 2f to 5f, respectively), as a result of intensive dust re-suspending from bedding, due to the increased airflow velocity in the house.

After comparison of airflow velocities and dust concentrations under different fan operating regimes, it can be concluded that, for air exchange in summer conditions, the optimal operating regimes are primarily 1st (23750 $m^3 \cdot h^{-1}$), and then 3rd (37300 $m^3 \cdot h^{-1}$) and 4th (39900 $m^3 \cdot h^{-1}$). In these three cases, along with optimal airflow velocities, the best effects of subjective feeling were achieved by intensive body heat drawing, while achieving the lowest concentration of both dust fractions.

Conclusion

Careful and detailed analysis of measurement results of dust concentration in the cow barn, with respect to the optimal fan airflow capacity requested in such buildings, it may be concluded that the best effects in dust concentration reduction were achieved by the lower fan rotation speeds. The first operational regime (23750 $m^3 \cdot h^{-1}$) of the ventilation systems is particularly favorable, but also acceptable are the third (37300 $m^3 \cdot h^{-1}$) and the fourth (39900 $m^3 \cdot h^{-1}$) regime. In those conditions very stable and effective dust concentration reduction was achieved, with airflow velocities that are within the optimal intervals for summer conditions (0.2 - 0.9 $m \cdot s^{-1}$).

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- Improvement of biotechnological procedures as a function of rational utilization of energy, agricultural products productivity and quality increase (TR 31051),
- Improvement and development new technological procedures in production of animal products, to achieve high quality and safe competitive products in market (III46009),
- Dynamical stability and instability of mechanical systems exposed to stochastic disturbances (OI 174011).

Raspodela koncentracija prašine u vazduhu objekta za krave pri različitim režimima ventilacije

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Rezime

Koncentracija čestica prašine je je važan mikroklimatski parametar koji karakteriše kvalitet ambijenta svakog stočarskog objekta. Povećana koncentracija prašine primarno utiče na kvalitet stajskog vazduha, a time i na zdravstveno stanje životinja i ljudi. Pored ostalih, intenzitet ventilacije je značajan parametar u kontroli prostorne raspodele koncentracija prašine u stočarskim objektima. Ovo je bio motiv autora da sprovedu istraživanje uticaja režima rada krovnih aksijalnih ventilatora (tj. intenziteta strujanja vazduha) na raspodelu koncentracija prašine u staji za vezao držanje krava. Tokom izvođenja ogleda ispitivan je uticaj šest različitih intenziteta strujanja vazduha u opsegu od 0 $m^3 \cdot h^{-1}$ do 48000 $m^3 \cdot h^{-1}$. Režimom rada ventilatora je upravljao elektronski kontrolni uređaj, kojim je određivano šest različitih brojeva obrtaja za dva krovna ventilatora, uključujući i neutralni režim (samo prirodna ventilacija). Koncentracija je merena na četiri visine (0,5 m; 1,0 m; 1,5 m i 2,0 m iznad poda), po tri poprečna i četiri podužna preseka objekta. Tako je dobijeno 48 pravilno raspoređenih mernih tačaka, koje su ravnomerno pokrivale unutrašnji prostor staje. Komparativnom analizom brzina strujanja vazduha i koncentracija prašine zaključeno je da ispitivani položaj ventilatora može da da zadovoljavajuće rezultate pri odgovarajućem režimu rada. Preporučeni su najpovoljniji radni režimi za upotrebu. Kao najpovoljniji izdvojen

je treći ispitivani režim sa protokom vazduha od 37300 $m^3 \cdot h^{-1}$, odnosno 25 h^{-1} ostvarenih izmena vazduha.

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