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OPTIMAL BARN PLANNING FOR HIGH YIELDING COWS UNDER HOT CLIMATIC CONDITIONS

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Background

A barn for milking cows should provide optimal ambiance for the cows to fulfill their potential of milk production. This goal is more challenging if the target animal is a high yielding cow that is characterized, in addition to milk yield, with higher body size. With such attributes, massive energy dissipation of the high milking cow is gradually becoming more challenging and stressing due to a global temperature increase (an increase of 4ºC in the last 40 years during summer was recorded, Israeli Meteorological Institute, personal communication).

Barn design significantly impacts cow behavior regarding heat stress, yet only limited pertaining scientific data is available in the literature. Much effort was invested in reducing heat stress by means of sprinklers and fans. Consequently numerous scientific publications were published during the last two decades concerning the direct effect of cooling on milk yield and fertility (Flamenbaum et al. 1986, 1995; Her 1988; Wolfenson 1988a, 1988b). The effects of several structural features, individually or combined, on ambient temperature at cow level in free stall barns was examined in several works (Nangia et al. 2000; Stowell et al. 2001; Kadzere et al. 2002). Tunnel ventilation was also compared to natural ventilation (Stowell et al. 2001). Under cold weather (below freezing) roof insulation combined with thermal curtains kept the inside barn temperature at 20ºC. Under hot weather it was found (Stowell et al. 1998) that the temperature inside the barn could be 1 to 3ºC higher than outside temperature. Insulated roof in a free stall barn reduced the temperature under the roof in comparison with a non insulated roof; yet, roof insulation had no effect on the temperature at cow level. Marginal height (side opening) of 3.2 m was inferior in reducing ambient temperature at animal level compared to greater heights (3.6-4.8 m), barn orientation was not reported (Bray et al. 1990). Orientation of a free stall barn with 4-rows with a 33% roof slope had no effect on ambient temperature at cow level.

Respiratory rate as an indicator for heat stress was used in few works (Berman 2005, Kadzere 2002). Roof slope of 30% reduced the difference between respiratory rate (RR) in the morning and in the afternoon in non-cooled cows (Armstrong et al. 1999). A marginal height of 3.6 m relative to 3.2 m was also found advantageous in measuring difference in RR between afternoon and morning. Opened gable-roof was found superior relative to capped gable-roof (Armstrong et al. 1999).

Respiratory rate is a physiological parameter that could be used to determine the optimal ambiance. However, it is practically impossible to measure the respiratory rate in commercial farms. Temperature humidity index (THI) is another indicator of stress, yet it ignores the influence of wind speed. A threshold temperature (TT) has recently been introduced. The TT determines the temperature at which a cow will start to increase the respiratory rate as a response to the development of heat stress. TT takes into account ambient temperature, relative humidity and wind velocity as well as milk yield and fur layer depth (Berman 2005).

The goals of this work were to determine optimum barn characteristics under the hypothesis that barn characteristics affect temperature-threshold (TT) which takes into account ambient temperature, relative humidity and wind velocity.

Materials and Methods

During the summer of 2004 and 2005, ambient conditions in 39 barns were recorded. two Meteorological stations were installed in each barn: one station inside the barn, at 2.2 m above bedding level; the other was installed at the same height downstream of the dominant wind at a distance that was approximately half of the characteristic length of the structure. A third station was placed 6 m above ground in an open field, away from obstacles. Ambient temperature (AT), relative humidity (RH), radiation, wind velocity and direction, and black bulb temperature were measured every minute, and averages of 10 min data were recorded using CR10 Micrologger® (Campbell Scientific Inc.). Measurements were conducted in each barn for 3 to 5 days during summer months. A heat-stress model that simulates the ambient temperature in which a cow would increase its respiratory rate as a response to the development of heat stress conditions was used (Berman 2005). The threshold temperature (TT) took into account: wind velocity, RH, AT. A cow producing 45 Kg milk daily with 3.5% fat; and with 3 mm fur layer depth was selected to represent a high yielding cow. A higher TT is advantageous to animal welfare.

Statistical analyses were based on GLM procedure of SAS (SAS 1992) with TT as the dependent variable. TT was calculated using the model developed by Berman (2005). Barn characteristics were used as independent variables for the temperature threshold model. The characteristics were: type of barn (free stalls vs. loose housing); orientation; marginal height; slope of the roof; type of roof (moveable roof vs. closed roof); ridge of the roof; width of barn; periods during day (morning, noon, evening, night). For the statistical analysis, continuous values were grouped into categories. Relevant interactions were also taken into consideration. The exterior data was used as a covariate. Only models that indicated probability lower than 0.05 were considered.

Results

The barns that were inspected in this survey were of the following types:

1. Corral – narrow lying area (5-8 m^2 per cow), surrounded by cement pavement (not shaded), often east-west oriented;
2. Loose housing – wide lying area (15-17 m^2 per cow), shaded;
3. Free stalls – free choice cubicles, shaded.

Corral type is currently used only in arid regions where the yearly precipitation is bellow 20 mm, and is becoming obsolete. The locally developed loose housing barn type is the most dominant.

Barn type

The TT for the corral structures was found inferior to the others, loose housing was superior, and the TT in free stall barn was accordingly in between (TT = 31.4ºC, 32.1ºC, 31.7ºC, respectively, $P < 0.05$). The TT was higher in loose housing compared to free stalls barn throughout most hours of the day.

Barn orientation

Wind direction was measured in each farm. In most farms the dominant wind was between 290º to 300º, i.e., during most of the day the wind direction was from the west. Orientation of the barns was grouped into two categories: north-south and west-east. Thus, structures positioned north-south were perpendicular to the dominant wind.

North-south direction was found to be superior relative to west-east (31.9 ºC vs. 33 ºC, $p<0.05$). This difference was consistent during most of the day except during the noon period (between 11:00 AM and 13:00 PM). The superiority of north-south was evident in both: loose housing and free stall barns but more prominent in free stall barns (the difference between the two direction categories was 1.5ºC in free stall barns while only 0.6 ºC in loose housing).

Roof ridge

Three kinds of roof types were examined: open gable roof; capped-gable roof; and a single slope roof. The later was found to be inferior with respect to its effect on TT, capped-gable roof came in second, and the open gable roof was the superior of the three, (single slope – 31.4ºC, capped-gable – 32.3ºC and 32.6ºC for open gable roof, $p < 0.1$).

Roof slope

Roof slopes were grouped to four categories: below 12%; between 12% and 19%; 20% to 22%; and over 22%.

Roof slopes below 12% were found inferior compared to other slopes, with TT difference of about 2.5ºC ($p < 0.05$). However, no significant difference was observed between the other roof slope categories. During the hottest hours of the day - roof slope above 20%

was found advantageous relative to lower slopes. No advantage was found to slopes higher than 22%

Side-opening

As the side-opening height increased the TT rose accordingly ($p<0.05$). Yet, combined side-opening height with structure orientation indicated that for north-south direction there was no advantage to side-opening of over 4.8 m ($p > 0.05$), while in structures that were west-east oriented there was a significant advantage to a side-opening of over 5.2 m ($p< 0.05$).

Barn Width

Barns were grouped by structure width to the following categories: (a) 19 to 30 m; (b) 30 to 41 m; (c) 42 to 51 m and; (d) above 52 m.

The TT of widths between 19 and 30 m was significantly higher than for widths over 30 m (33ºC vs. 31.5ºC, $p < 0.05$), but, when considering interaction between width and orientation it was found that this result is only valid for structures that are west-east oriented, while TT for north-south oriented structures was maximized at 42 to 51 m ($p<0.05$). Higher width in the latter was found inferior, having the same effect as widths below 42 m.

Roof type

Due to environmental regulations cows are not allowed to assemble out in an open yard during rainy season (October to April). These regulations prompted the development of the mobile roof. This technology allows removal of the roof when body temperature is higher than the ambient, thus enabling heat dissipation to open sky. Two types of removable roofs were developed:

(a) sliding roof – the lower, moveable, section of the roof is pulled up to be stored under the fixed section of the roof;

(b) shutter roof – which allows control of the angle of the shutters to accommodate direction of solar irradiation.

In this work four roof types were compared: conventional single or double slope roofs and the above mentioned removable roofs.

Sliding roof was found to have a significantly higher TT than for all other roof types ($p<0.05$). No significant difference was observed between shutter and conventional double slope roof. Interaction between roof type and structure orientation indicated similar results for north-south oriented barns, but for east-west oriented barns the TT of shutter and sliding roof was very similar ($p > 0.05$) while both opened roofs were inferior relative to regular roof.

Discussion

About six years ago, a constitutional reform in cattle husbandry management was applied in Israel to comply with contemporary environmental regulations aimed to prevent water and soil contamination caused by waste seepage. The new regulations banned cattle presence in open yards. As a result, a multitude of barns, of various types, measures, orientations, and roofing type technologies were erected.

Under hot conditions and natural ventilation, the respiration rate of a cow will increase earlier in free stall barns compared to loose housing. This can be partly explained by increased congregation in free stall barns, but it could also be due to presence of additional structural elements, such as dividers, columns, and embankments that are typical to free stall barns and serve as obstacles to crossing wind. This claim was also supported by the difference in threshold temperature between north-south and west-east that was higher in free stalls compared to loose housing with an advantage to structures that were perpendicular to prevailing wind (1.5ºC vs. 0.6ºC, respectively).

Opened barns are ventilated mainly by natural air flow which has significant influence on TT. This assumption was supported by the fact that ambient temperature and relative humidity were not significantly differed between the two sides of the barn that were oriented north-south, while the air speed was significantly decreased during wind passing through the barn. These results were not in agreement with temperature measurements near the cow if wind speed is ignored (Stowell et al. 2001). Cow congregation might also be influenced by wind speed. This is compatible with observations which show that cow congregation is less severe in north-south compared to east-west orientations.

We found that the orientation of the barn in relation to dominating wind has significant effect on relief of cow’s heat stress both in loose housing and free stalls. This finding is compatible with Barrington et al. (1994).

Side opening of the barn should be determined according the structure orientation. Barns that are oriented perpendicular to dominant wind require lower side opening, compared to structures that are parallel to dominant wind. The inferior ventilation in parallel structures could be compensated by increased roof height. Our results augment the conclusions derived by Bray (1990) and Stowel (1994).

Optimal structural width is also dependant on structure orientation: structures that are parallel to wind direction should be narrower compared to structures that are perpendicular.

Zappaviga (2002) demonstrated that ventilation derived by the wind is the dominant factor for environmental control. Proper barn orientation and matching height of side wall will contribute to animal condition. These results are in agreement with our findings.

Increased roof slope contributed to the reduction of animal stress by up to 22%. Aside from this, unlike findings by others (Armstrong et al. 1999; Nangia et al. 2000),increased slope, was not found to contribute in further improvement of animal conditions.

Our results support the advantages of an open gable roof weighed against capped-gable roof as reported by Armstrong (1999).

As previously mentioned, opened roof technology was developed in Israel to accommodate new regulations aimed to reduce environmental contamination. Two techniques were developed and adopted: sliding roof; and shutter roof. Our results showed advantage to sliding roof with respect to minimizing animal heat stress. We suggest that by sliding the roof, the actual width of the structure is reduced, which contributes to improve climatic conditions inside the barn.

Summary

This study was the first to employ a novel heat stress model that augmented other contemporary models by taking into account the effect of wind velocity. Our study demonstrated that:

(a) Of the common barn types in Israel, loose housing proved superior to free stalls and corrals.

(b) Barns should be oriented in such a way that longitudinal axis is perpendicular to the direction of the dominant wind.

(c) Side openings should be at least 4.8 m. For barns that are oriented parallel to prevailing wind, side openings should exceed 5.2 m.

(d) No advantage was found in roof slope beyond 22%.

(e) Barn width is limited by its orientation. Barns positioned with longitudinal axis perpendicular to prevailing wind can be wider than barns that are parallel to wind.

(f) Opened gable roofs proved advantageous compared to capped-gable roofs.

(g) Open roof technology improves climatic conditions for the animal. Among the existing systems, sliding roof was advantageous to shutter roof.

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