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HOW TO RECTIFY DESIGN FLAWS OF DAIRY HOUSING IN HOT CLIMATES?

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ABSTRACT Small dairy farms in hot climates are encountering several problems caused by design flaws of the implemented housing designs. Consequently, heat stress increase and milk yield dramatically decreases, which leads to economic deficiency of the farm. One key issue is to develop simple means to rectify the design flaws with minimum costs. In order to develop feasible means, design flaws were detected in 14 small dairy farms in Egypt to exemplify the flaws of housing designs in arid and semi-arid zones. A package of interconnected solutions is suggested to rectify the design flaws. Subsequently, the maximum temperature, dry-bulb temperature, black-globe temperature, dew point, relative humidity, shaded area, and air velocity were measured inside the rectified vs. non-rectified cowsheds and compared after conducting the statistical analysis. On the other hand, the Temperature-Humidity Index (THI) and Black Globe Humidity Index (BGHI) were calculated to find out the level of heat stress affecting the dairy cows. Furthermore, the milk yield, respiration rate, skin temperature, feed intake were recorded and compared. Moreover, the costs of the developed means were calculated and a feasibility study was carried out. The results showed that the developed means are effective and feasible, where the heat stress decreased (THI decreased from 94.6 to 83.7; dry-bulb temperature decreased from 42.7 to 33.6 ^{o}C) and the average milk production increased from 18 to 26 kg/day.cow. Consequently, the costs were minimized and the revenues were maximized, which achieve economic efficiency for the farm where the profit increased by about 427 $/cow.year.

Keywords: Heat Stress, Shade Structure, Roof Material, Cowshed Height, Shading Efficiency, Microclimate, Climate in Dairy Housing, Cooling System, Milk Yield, Costs.

INTRODUCTION Open housing system is used in hotter climates, with varying systems of protection from heat stress, depending on the ambient temperature. An open housing system, in hot climates, consists of a yard shaded by a roof. This system allows air to move in the space between the roof and the floor performing natural ventilation which enhances dairy cows' microclimate (Hatem et al., 2004a; Hatem et al., 2004b; Hatem et al., 2006). However, the cowshed height should be between 5 and 8 m, preferably 8 m if the cowshed width is greater than 24 m (Hatem et al., 2004a; Samer et al., 2008d). Moreover, the best suited roof materials for arid and semi-arid zones are reed and straw mats which are economically feasible. In addition, the shading efficiency should not be lower than 85% and the shade structure should be oriented east-west where the largest area of the structure should face the prevailing summer winds to allow better aeration, and the distance between two cowsheds should never be shorter than 15 m to avoid carrying the contaminated air from one cowshed and spreading it into another one (Hatem et al., 2006; Samer et al., 2008b; Samer et al., 2008d). Anyhow, the cows' standing level should be lower than the level of the feeding bunk by about 20 cm (Hatem et al., 2009). Furthermore, the micro-sprinklers and fans cooling system is more applicable in arid and semi-arid zones than the fog cooling system; especially, in open housing systems. In contrast, fog (mist) cooling system should be installed where relative humidity levels are reasonable, and in total or semi-confinement systems (Samer et al., 2008c). However, Samer et al. (2008a) stated that the manure should be weekly scraped from the corrals (loose yards). This study aims at surveying the management deficiency and design flaws of dairy housing in hot climates, especially arid and semi-arid zones, and then proposing simple and feasible solutions in order to provide better microclimate which ultimately results in increasing the productivity of the animals, i.e. the milk yield.

MATERIAL AND METHODS The problems were surveyed in several dairy farms. Subsequently, various solutions were developed and tested.

Surveyed Problems A survey of design flaws and management deficiency has been carried out in 14 small dairy farms. The survey's results can be summarized as follows:

- **Shading.** The shade structure does not provide the required 85% shading (Fig. A.1a), as consequences the cows are crowded under shed in a small shaded area and the contact area among cows' bodies increases, as results the heat stress increases due to the increasing heat exchange; in addition, several injuries were noticed on cows' bodies.
- **Maintenance.** The roof covering materials are not maintained periodically (Fig. A.1b, and A.1c), which leads to expose the cows to direct sun radiation, increase sun intrusion, and reduce shading efficiency.
- **Covering Material.** Corrugated aluminum still widely used as a covering material for the roof of shade structures (Fig. A.1d), though they have high thermal conductivity which increases the heat stress that affects dairy cows. This is eventually decreasing the milk yield.
- **Youngstock Housing.** The youngstock are housed in metal boxes (Fig. A.1e) covered with metal sheets (Fig. A.1f), which affects the growth and causes death in some cases when these boxes are exposed to direct sun radiation, other farms place the boxes under shade to reduce heat stress.
- **Feeding bunk.** Several small dairy farms are having a concrete base where the level of the feeding bunk is the same of the cows' standing level and sometimes is lower (Fig. A.1g), which forces the cows to exert efforts to reach the forage distributed into the feeding bunk i.e. uneasy-reach forages.
- **Feeding Line.** Some farms do not have concrete feeding line, i.e. the feeding line is sandy (Fig. A.1h), as result the dust emission increases which affects the respiratory system of the youngstock and the dairy cows.
- **Water Trough.** Water leakage from the water troughs is noticed in several farms, which wets the surrounding sand floor (Fig. A.1k). The problem is when the cows lay down on a wet floor, their udders may be infected and encounter mastitis.

Another problem is that water troughs are in some farms exposed to direct sun radiation i.e. the cows are drinking hot water, this increases heat stress.

- **Cooling System.** Fog cooling system is widely installed and without fans (Fig. A.1l, A.1m, and A.1n). However, this cooling system is not suitable for the open housing system where the fog system is installed. Furthermore, this cooling system is inefficient under open housing conditions because of the external air which naturally flows inside the open housing and take out the cooled air which surrounds the cows to the outside of the cowshed leaving the cows without cooling, i.e. under heat stress. This is due to the fact that fog cooling system is designed to be mounted directly under the shade structure, i.e. above the cows by about 2.5 m (Fig. A.1l); where this system follows the theory of indirect cooling, in other words, it cools the air surrounding the animal but not the animal directly.
- **Manure Handling.** The manure is scrapped monthly and seasonally in some farms (Fig. A.1g), which results in contaminating the cow's body and increasing the possibility of infecting the cow's udder by mastitis. Another result is increasing the standing level of the cows to be the same as or higher than the feeding bunk level.

Developed Solutions Several solutions were developed to rectify the design flaws and management deficiency of dairy farms in arid and semi-arid zones. The solutions were implemented in the dairy farm under consideration where the experiments were carried out and can be represented as follows:

- **Shading.** Textile was installed to cover the unshaded areas (Fig. A.2), as a result the shading efficiency increased in comparison to non-rectified shed (Fig. A.3).
- **Maintenance**. The cowsheds having straw or reed mats as covering material, their roof covering material was checked weekly and maintained when necessary.
- **Covering Material.** The cowsheds that have metal (e.g. corrugated aluminum, metal sheets, etc...) as roof covering material were covered by straw bales as insulation material over the roof, which decreases the convective and radiative heat transfer from roof to cows. Furthermore, the straw bales were checked weekly and maintained when necessary.
- **Youngstock Housing.** Textile was installed on lateral posts to cover the youngstock metal boxes, which results in reducing their negative thermal effects on youngstock.
- **Feeding bunk.** Usually the feeding places (where the cows stand to reach the feeding bunk) are sand floor which is the extension of the sand corral/yard. On the other hand, the feeding bunks are concrete. The sand feeding places were re-levelled to be lower than the feeding bunk level by about 20 cm in order to provide easy-reach forages.
- **Water Trough.** New waterproof plastic troughs were installed under shade, and the old troughs were removed. The new troughs were checked regularly for leakage.
- **Cooling System.** Fog cooling system was modified to micro-sprinklers and fans cooling system (Fig. A.4), by carrying out the following steps: (1) new fans were installed 40 cm over the cows, (2) the water line of the fog system was removed and reinstalled directly under the fans, (3) the foggers were replaced by half-circle (180^o) micro-sprinklers, (4) the pressure was reduced from 160 psi to 25 psi, (5) the nozzle's discharge was increased from 7.6 gph to 30 gph, and (6) the other cooling system components (thermostat, timer, water line, filter, solenoid valve, and pressure reducer) were kept without modifications.

- **Manure Handling.** Manure was weekly scraped from the sand corrals using a scraper mounted next to tractor.

Testing the Developed Solutions Two similar cowsheds i.e. both have the same specifications, which are: (1) shed height is 3.5 m, (2) allotted area per cow is 20 m^2/cow, (3) orientation is east-west, (4) shade structure is steel fame with corrugated aluminum as roof covering material, (5) sand floor corrals system, and (6) each cowshed houses 10 Holstein Friesian cows. The cowsheds were selected in the same dairy farm in order to ensure that they are under the same climatic conditions (wind speed and direction, external temperature and relative humidity, and sun radiation). The first cowshed, which had the aforementioned design flaws, remained without modification (Fig. A.3). The design flaws of the second cowshed were rectified according to the developed solutions (Fig. A.2). The experiments were carried out in a small dairy farm (20 cows) 150 km North-West of the Egyptian capital Cairo, at longitude 29^o59' E and latitude 30^o42' N, during summer months (May – June – July – August – September of year 2009). The measurements were performed one day a week (each Friday), five times along daytime in 3 hours intervals (07:00 am – 10:00 am – 01:00 pm – 04:00 pm – 07:00 pm).

The measurements were divided into measurements on cowsheds, measurements on microclimate, and measurements on animals. The whole measurements were quantified inside both cowsheds at the same time. All data were evaluated using the SPSS program and histograms were represented by the Microsoft Excel. The measurements on cowsheds were shading areas under the sheds. The shading efficiency was calculated for each shed five times a day by measuring the shaded area under each shed and divided by the roof area multiplied by one hundred. The measurements on microclimates were maximum temperature, relative humidity (RH %), dry-bulb temperature, black globe temperature, dew point, and air velocity. The measurements on animals were rectal temperature, skin temperature, respiration rate, milk production, and feed intake.

Regarding the cowsheds, shaded area under sheds was measured by a tape. In relevance to the climate in dairy housing, maximum temperature was measured by max-min thermometer; relative humidity, dew point, and dry-bulb temperature were measured by digital hygrometer-thermometer device, and air velocity was measured by vane anemometer at the same aforementioned time intervals. Concerning the dairy cows, Hatem et al. (2004a) Mentioned that skin and rectal temperatures and respiration rate increase with the increasing of the ambient temperature; consequently, rectal temperature was measured by digital thermometer. The skin temperature was measured by infra-red thermometer. The respiration rate (breaths/minute) was determined by timed visual counting of flank movement. The milk production was recorded for each cow by the farm central computer which receives data from the milking parlour by a luminous fibbers cable, and feed intake was recorded in the farm central computer.

Two means were implemented to estimate heat stress; the first one is computing the Temperature-Humidity Index (THI):

$$\mathbf{THI = T_{db} + 0.36\ T_{dp} + 41.2} \qquad (1)$$

where, T_{db} is dry-bulb temperature (^{o}C) and T_{dp} is dew-point temperature (^{o}C).When THI is less than 72 there is no stress, between 73 and 77 there is a mild stress, between 78 and

88 there is a significant stress, between 89 and 99 there is a severe stress. If THI exceed 99 possible death occurs (Keown and Grant, 1999; Stowell et al., 2001; Meyer et al., 2002). THI was computed for both sheds and the results were compared between them.

The second mean is to calculate the Black Globe Humidity Index (BGHI). Buffington et al. (1981) proposed a BGHI by replacing the dry bulb temperature in equation (1) with a black-globe temperature. The BGHI is expressed as:

$$\mathbf{BGHI = T_{bg} + 0.36\ T_{dp} + 41.2} \quad (2)$$

where, T_{bg} is the black globe temperature (^oC) and T_{dp} is the dew point temperature (^oC). The black-globe temperature was measured with a black globe thermometer made of a black copper ball about 15 cm in diameter with a temperature sensor inside. The black globe integrates the effects of air temperature, solar radiation and convective cooling due to wind into a temperature value. Regarding BGHI, the heat stress is classified into four general categories: Normal (BGHI < 74), Alert (74 < BGHI < 78), Danger (78 < BGHI < 84) and Emergency (84 < BGHI).

RESULTS AND DISCUSSION The averages of the different measurements throughout the summer (Table 1) show that the developed solutions created significant differences in the cows' microclimate. In addition, Figure 1 shows highly significant differences among averages of maximum temperatures measured inside both cowsheds through summer months. Consequently, the milk yield increased from 18 to 26 kg/day.cow as average of 10 cows in different production stages, i.e. in different DIM and seasons. Hence the profit is 8 kg/day.cow calculated for 305 days/year. The milk revenues were 634 $/cow.year, and the total costs of the developed solutions were 54 $/cow.year (Table 2). Due to enhancing the microclimate and reducing the heat stress, the feed intake increased by about 20%, where forage costs increased by 153 $/cow.year. Therefore, the profit was 427 $/cow.year. The cost details are represented in Table 2.

Table 1. Average of the measurements at peak time through summer months ($p < 0.05$).

Measurements	Non-Rectified Cowshed	Rectified Cowshed
Dry-bulb Temperature (^oC)	42.7	33.6
Relative Humidity (%)	39.1	48.7
Temperature-Humidity Index	94.6	83.7
Black Globe Humidity Index	95.5	83.9
Air Velocity (m/s)	0.6	1.1
Shading Efficiency (%)	35	89
Rectal Temperature (^oC)	39.6	38.7
Skin Temperature (^oC)	38.5	35.3
Respiration Rate (breath/min)	86	77

The relative humidity increased due to the cooling system modifications which changed the indirect cooling effect to direct cooling by sprinkling the cows directly. In contrast, the dry-bulb temperature decreased due to the combined effects of cooling, roof insulation, and the increased shading efficiency. The results shown in Table 1 are in agreement with Hatem et al. (2006), Samer et al. (2008b), Samer et al. (2008c), and Samer et al. (2008d). Moreover, THI changed from severe to significant stress, and BGHI changed from emergency level to danger. However, the heat stress can be extremely reduced if it is possible to increase cowshed height from 3.5 m to 5 or 8 m according to the cowshed width, but this step is unpractical in case of an already existing structure as in this farm; therefore, this specification raised by Hatem et al. (2004a) is unachievable.

An important parameter that should be taken into consideration to determine the effectiveness of the developed solutions is the maximum diurnal temperature inside both cowsheds. Figure 1 shows that maximum temperature was effectively decreased when the developed solutions were implemented. The differences were found highly significant.

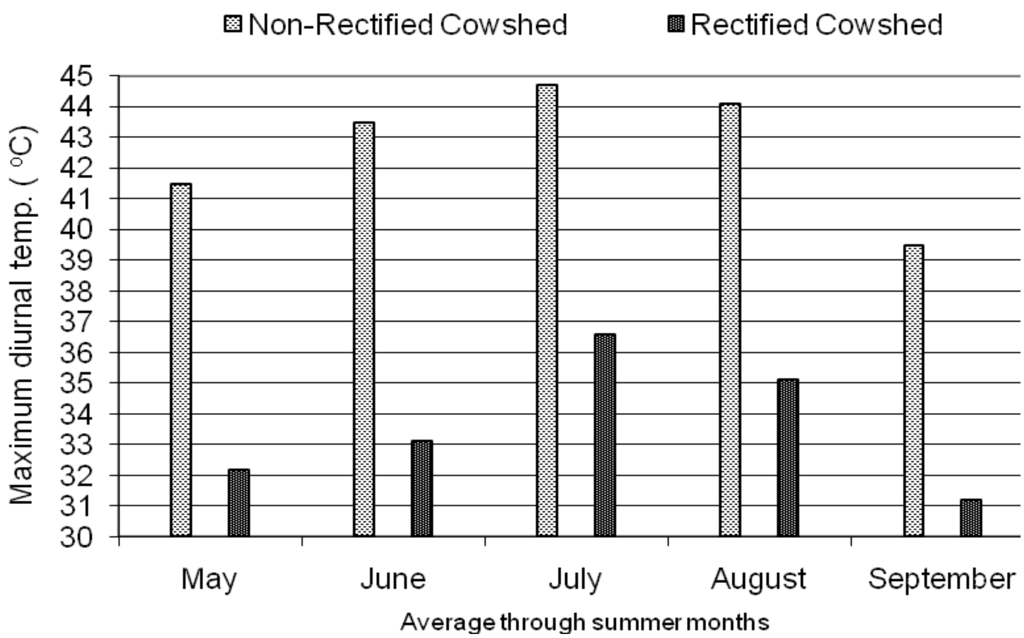

Figure 1. Maximum temperature inside both sheds through summer months ($p < 0.01$).

The capital investment with the fixed, variable, and total costs of the implemented solutions/modifications are represented in Table 2. The values were calculated as total for a cowshed that houses 10 dairy cows. Although the modifications of the cooling system represent the major portion of the capital investment, they are highly required due to their immense positive effect on reducing heat stress. On the other hand, manure handling consumes the main part of the variable costs; nevertheless, manure handling is essential to provide sanitary clean corrals.

Table 2. The required capital investment with the fixed, variable and total costs.

Items	Capital Investment ($)	Lifetime (year)	Fixed Costs ($/year)	Variable Cost ($/year)	Total Costs ($/year)	Total Costs per Cow ($/cow.year)
Textile (incl. Youngstock)	110	3	36.67	15	51.67	5.17
Maintenance	-	-	-	50	50	5
Re-levelling	-	-	-	20	20	2
Water Trough	55	5	11	3	14	1.4
Cooling System Modifications	857	5	171.4	22	193.4	19.34
Manure Handling	-	-	-	210	210	21
Total	1022		219.07	320	539.07	53.91

CONCLUSION Rectifying design flaws and management deficiency of small dairy farms located in arid and/or semi-arid zone enhances the microclimate and cow comfort. Consequently, the milk yield increases. On the other hand, implementing the suggested solutions and simple means to fix the design flaws was found to be economically feasible. Therefore, the rectification costs were reasonable in comparison with the enormous milk yield increment which ultimately results in privileged annual profit per cow.

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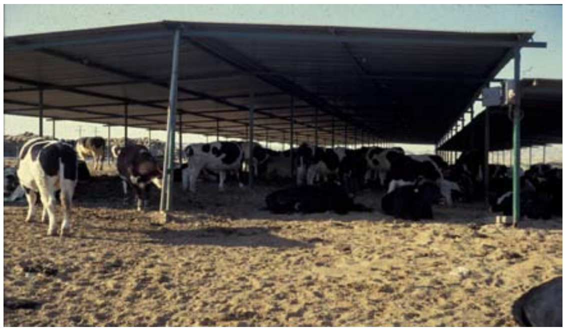
APPENDIX A

(a)

(b)

(c)



(d)

(e)

(f)

(h)

(g)

(k)

(m)

(l)

(n)

Figure A.1. Design flaws of dairy housing in arid and semi-arid zones.

Figure A.2. Rectified cowshed.

Figure A.3. Non-rectified cowshed.

Figure A.4. Modified fog cooling system to micro-sprinkler and fan cooling system.