Heat transfer into stable environment through the various types of roofing

Wärmeeintrag in den Stallraum durch verschiedene Dachkonstruktionen

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Keywords: dairy cows, housing, roofing, heat stress
Schlüsselwörter: Milchkühe, Aufstallung, Dachkonstruktion, Hitzestress

Summary

The object of research was to determine the effect of differently solved roof deck in stables for livestock on warming the interior, especially in the summer. There was found a high correlation between the intensity of solar radiation and heat transmission into stable environment. Results of measuring the efficiency of heat transfer show large differences in heat transmittance according to the used material of roofing. There was observed 8 different variants of roof covering. The best result (lowest heat transmission into the stable environment) was achieved through insulated sandwich panel, which transmitted into the stable environment only 16.5 % of solar radiation. Trapezoidal aluminum roof panel transmitted only 22.0 % of solar radiation. Fiber-cement roof panel was approximately transmitted 34 %. Translucent panels of polycarbonate and transparent fiberglass transmitted 86.8 % resp. 99.2 %, where almost all the heat was transmitted from solar radiation into the stable environment.

Zusammenfassung

Ziel der Untersuchungen war es, den Einfluss verschiedener Dachaufbauten auf die Erhöhung der Stallinnentemperatur, vor allem in den Sommermonaten zu bestimmen. Zwischen der Intensität der Sonneneinstrahlung und dem Wärmeeintrag in den Stallraum wurde eine hohe Korrelation gefunden. Die Messungen zur Wärmeübertragung bei acht verschiedenen Dachaufbauten zeigten große Unterschiede. Das beste Ergebnis (kleinster Wärmeeintrag in den Stallraum) erzielte ein wärmegedämmtes Sandwichpanel, bei dem nur 16,5 % der Solareinstrahlung eingetragen wurden, gefolgt von trapezförmigem Aluminiumblech mit 22 % und Faser-Zement-Platten mit 34 %. Durchsichtbare Panele aus Polycarbonat- oder transparentem Glasfaser-Material erreichten Werte von 86,8 bis 99,2 %, d. h. fast die gesamte Sonneneinstrahlung wurde in den Stallraum weitergeleitet.

1 Introduction

Microclimate in stables for livestock production significantly affects the health, performance and vital signs of the animals. The adverse effects of hot environmental conditions on the performance and welfare of dairy cows are well known (ST-PIERRE et al. 2003). Cows with elevated body temperature exhibit lower dry matter intake and milk yield and produce milk with lower efficiency, reducing profitability for dairy farms in hot, humid climates (WEST 2003). Cows under heat stress have reduced duration and intensity of estrus, altered follicular development, and impaired embryonic development (JORDAN 2003). Hot conditions negatively affect rumination time and modify its daily pattern (SORIANI et al. 2013). Especially in the summer, during high temperatures period is the situation critical and farmers must take steps to reduce heat stress of animals. Heat from solar radiation gets into the stable environment through the roof deck. The scheme of heat transmission from the solar radiation is shown in Figure 1. From this scheme it is evident that only a portion of the heat from solar radiation gets into the stable environment. Portion of solar radiation gets into the stable environment directly (in case of transparent material of roofing), portion reflects back to the exterior and portion is absorbed by the roof deck and subsequently radiated to the interior and exterior. Reducing thermal radiation on shaded animals reduces heat stress independently of other means of stress relief (BERMAN and HOROVITZ 2012). For this reason it is very important to make the right decision on the roofing to minimize the heat transfer from the solar radiation.

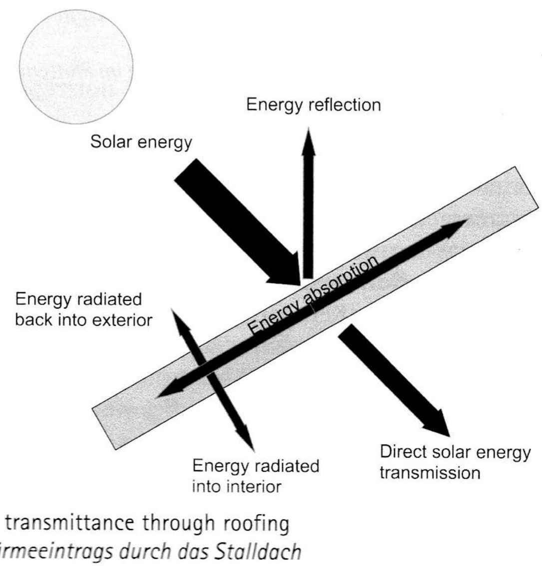


Fig. 1: Scheme of heat transmittance through roofing
Abb. 1: Schema des Wärmeeintrags durch das Stalldach

2 Materials and Methods

To determine heat transfer into the barn through the roof covering we applied method based on the accumulation of heat gain from solar radiation in the plate heat exchanger. Water was used as a solar energy storage medium. This method is based on the accumulation of heat gained from sunlight using heat storage collector whose main part is a thin-walled plate heat exchanger (similar to the heat exchanger used for tanks with direct cooling of milk) painted matte black color with adjustable flow control. The heat exchanger was placed inside a polypropylene case insulated with polystyrene plates (see scheme in Figure 2).

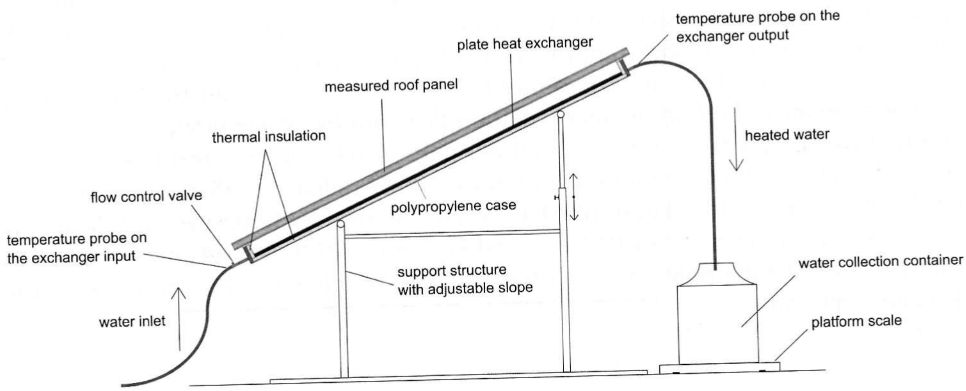


Fig. 2: Scheme of an apparatus for measuring of heat transmission through the roofing panels using heat accumulation in the plate heat exchanger
Abb. 2: Anlageschema einer Wärmeeintragsmessung bei Dachplatten im Plattenwärmetauscher

Weather conditions were measured with weather station Davis Vantage pro 2, located close to running experiment. Solar radiation intensity on roof panels' surface was farther measured with pyranometer CTM SG010 with Comet S5021 data logger. Inlet and outlet water temperature was measured with Ni1000 temperature probe with universal logger Almemo 2290-4. Water flow, resp. weight of outlet heated water in time, was measured with digital platform scale Kern DE150K50N connected to notebook.

The collector was placed on support structure allowing slope and orientation adjustment. By default, the structure faces south with an inclination of 22°, this roof slope is most commonly used on new stables. Heated outlet water is collected in container placed on the platform scale. Measuring scheme is shown in figure 2.

Water flowing through the heat exchanger accumulates heat energy obtained from solar radiation on the surface of the measured roof panel. Inlet water has temperature T_1 and is heated at a specified flow rate (approximately 1 kg min^{-1}) to a temperature T_2, measured in the outlet of the exchanger.

Amount of heat transferred through the roof panel is based on temperature change ΔT and total amount of heated water during the measurement time t. Quantity of heat Q is expressed by the following equation:

$$Q = c\ m\ \Delta T\ [kJ] \tag{1}$$

where Q is the amount of heat transferred through the roof panel in kJ, c is the specific heat capacity of water in $kJ\ kg\ K^{-1}$, m is the mass of heated water in $kg\ h^{-1}$, ΔT is the inlet and outlet temperature difference ($\Delta T = T_2 - T_1$) *in Kelvin.*

The efficiency of heat transfer is expressed as ratio between output and input of collector. In this case, input is amount of heat consumed for water heating Q adjusted in Wh as Q_1:

$$Q_1 = Q / 3,6\ [Wh] \tag{2}$$

Total energy from solar radiation E on roof panel surface during the measurement time is expressed by the equation:

$$E = SR\ S\ t\ [Wh] \tag{3}$$

Where SR is the intensity of solar radiation in $W\ m^{-2}$, S is the surface of heat exchanger in m^2, t is the time of measurement in hours.

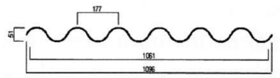
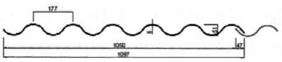
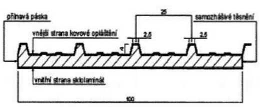
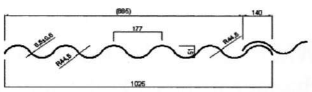
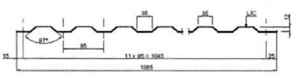
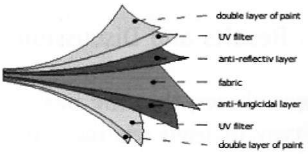
Efficiency μ is then expressed as:

$$\mu = Q_1 / E\ [\%] \tag{4}$$

3 Results and Discussion

It was shown that the heat transfer through the roof covering significantly depending on type of used roofing. The results of selected roofing panels are summarized shown in the graph in Figure 3. The best result (lowest heat transmission into the stable environment) was achieved through insulated sandwich panel, which transmitted into the stable environment only 16.5 % of solar radiation. Surprisingly good result was found through the trapezoidal aluminum roof panel, which transmitted into the stable only 22 % of solar radiation. This can be explained by the fact, that polished metal surface has low emissivity and high portion of the solar radiation reflects back to the exterior. Partly translucent white covering fabric let only small portion of solar radiation through directly, white color reflects significant portion of solar radiation back to the exterior. Efficiency of heat transfer through white covering fabric was 31.6 %. Fiberglass roof panel of grey color lets through 33.1 % of solar energy. Efficiency of heat transfer through the fiber-cement roof panel was approximately 34 %. From the point of heat, transfer translucent panels of polycarbonate and transparent fiberglass were the worst, the efficiency of heat transfer was 86.8 %, resp. 99.2 % and almost all the heat was transferred from solar radiation into the stable environment.

Tab. 1: Basic information of measured roofings
Tab. 1: Die Grunddaten der Dachkonstruktionen

Type of roofing panel	Material	Color	Preview
Elyonda	Fiberglass	grey	
Elyplast	Fiberglass	transparent	
Translucent polycarbonate	Polycarbonate	transparent	
Sandwich insulated panel Brollo Agro TV5	PUR foam / metal cover	light grey	
Fiber-cement panel	Based on cement reinforced by organic fibers	brick red grey	
Trapezoidal metal panel KOB 1012	Aluminium	polished aluminium	
ProfiCover	Fabric	white	
	Fabric	white	

Results confirmed ARMSTRONG (1994) review of shades for cows and his suggestions in prevention of heat stress. WEST (2003) states, that one of the first steps that should be taken to moderate the stressful effects of a hot climate is to protect the cow from direct and indirect solar radiation. Shading is one of the more easily implemented and economical methods to minimize heat from solar radiation (BOND AND KELLY, 1955). Based on obtained results need to carefully consider the size of translucent surfaces of the roof deck due to the lighting requirements and elimination of heat stress from solar radiation. Besides the heat transfer selected panels vary their cost, duration, maintenance and structure requirements.

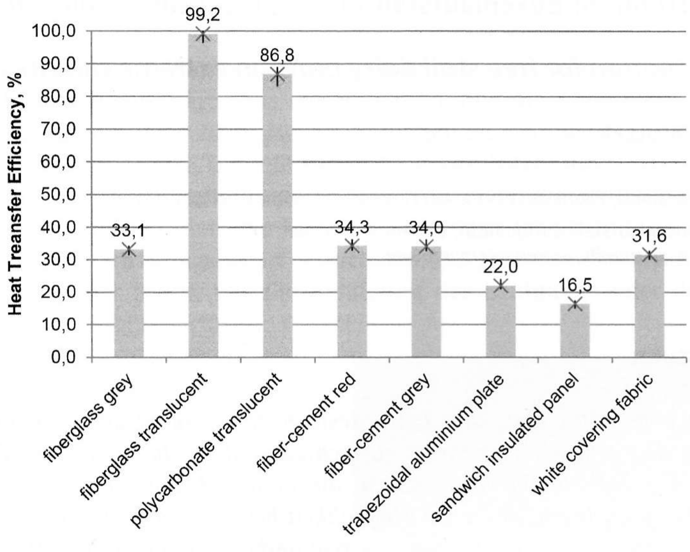


Fig. 3: Heat transfer efficiency of different types of roofing panels
Abb. 3: Wärmeeintragseffizienz für verschiedene Dachplatten

4 Conclusions

The above results show that material of roof covering and its thermal insulation properties influence the heat transfer from solar radiation into the stable area significantly. Transfer of heat can be effectively reduced by using thermal insulation of roof covering and surface finishing of roofing material with high reflectivity of solar radiation. Translucent roof panels let almost all the solar radiation through. If needed, according to the light requirements, they should preferably be placed in that part of the roof, which is not directly lit in the time of highest intensity of solar radiation (preferably north side). Their placing at the top of the roof and alternating arrangement with non-translucent panels can be recommended.

Literature

The literature can be requested from the authors.

Acknowledgments

This work was supported by a grant-in-aid (RO0614) from The Ministry of Agriculture of the Czech Republic.