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Heat radiation through various roofing materials in a livestock housing model

The roofs of naturally ventilated livestock housing are often of very simple construction, the main aim being protection from precipitation. Often neglected because of the increased costs involved is insulation against heat radiation into the building through intense sunlight heating-up the roof. Hereby a roof model was tested to discover the effect of "shadowing" one layer of trapezoidal metal sheeting by a further layer of the same material. In all tests radiation on the roof represented 1 000 W/m^2 over two hours. Most important parameters were the heat radiation in the model interior space area as well the interior temperature. Where the focus is on minimising costs, the doubled trapezoidal roof proved an acceptable alternative method of preventing excessive heat radiation through the roof into livestock buildings.

Keywords
roof material, heat radiation, naturally ventilated housing

Abstract
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In our latitudes, the roofs of naturally ventilated dairy cow housing should be aimed mainly at protection against moisture and from direct radiation from the sun; often discussed are so-called shading roofs. While simple roofs, e. g. of trapezoidal metal sheeting, are very easy to erect, they have the disadvantage of heating-up quickly through solar radiation and then emitting relatively high amounts of energy as radiant heat into the barn interior and therefore onto the cows. Often forgotten is a second disadvantage of simple single-layer metal sheeting: at night the roof material cools just as quickly as it heats up and is then significantly colder as the warm moist air of an occupied barn. This causes condensation which can lead to serious health problems for the animals involved. Simple help here can be achieved through covering the first layer with a secondary (thin) roofing layer [1] ensuring a reduction of heat radiation through the day and also of heat loss during the night. Also avoided hereby is the formation of condensation water on the inner surfaces of roof and outer walls. The advantages of roofing with trapezoidal sheeting are, however, the low costs involved and the rapid, uncomplicated, erection [2].

Just as easy is roof construction with sandwich panels laid out in the same way as trapezoidal metal sheeting. Even with a minimal insulation of 30 mm this roof covering offers sufficient insulation for livestock. Using sandwich panels with insulation in roof construction is therefore an elegant solution with comparatively little labour input for reducing heat build-up and emission. However, sandwich panels cost about six times as much as representative trapezoidal sheets. For this reason the study presented here used a trial model to observe the effects of "shadowing" a single trapezoidal sheeting by adding another layer of the same sheeting.

Experiment design and method

The study was based upon a trial model from the Institute for Thermal Insulation e.V. (FIW) in Munich which at the request of the Industrial Association for Polyurethane Rigid Foam (IVPU, Stuttgart) e.V. had conducted investigations into summer room climate conditions in accommodation immediately under the roofs of houses [3]. This model, redesigned and adjusted for integration into a solar simulator, was available from the Institute for Agricultural Engineering at Hohenheim. Dimensions were 650 x 595 x 400 mm (width x depth x hight). Because an unheated barn was to be simulated, insulating material for the walls was omitted, those being constructed only of 4 mm thick plywood.

Investigations were conducted in an experimental stand using artificial sunlight. The selected solar radiation level was 1 000 W/m^2. Three different roof coverings were compared: sandwich panels, single trapezoidal sheeting and double trapezoidal sheeting, each material being cut for the experiment to a size of 625 x 575 mm. This allowed the roof elements to fit securely onto the model's timber framework so that heated air from the interior could not escape upwards. The sandwich panel comprised a heat insulating construction unit with a core of PUR rigid foam. The outer surfaces were of strip galvanised sheet steel with red-brown outer colouring (RAL 8004). The inner lining was structured aluminium foil with grey-white colouring (RAL 9002). The thickness of the outer sheeting was 0.6 mm and of the aluminium a little less at 0.5 mm. The insulation core was 30 mm thick and FCKW-free (Profiltec Sandwich, 2011). The markings in **Figure 1** indicate the cutting edges for the roof.

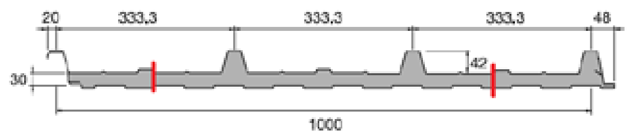
Trapezoidal metal sheeting was used as second roof covering with outer colour similar to that of the sandwich panels so that the colour could not lead to marked differences in roof temperatures. For the trial the sheeting was cut in such a way that two positive narrow corrugations each with a breadth of 115 mm were positioned within three negative corrugations each of 135 mm. The red markings in **Figure 2** indicate the cutting lines lengthways.

The third variant tested was double trapezoidal metal sheeting. The material used was the same as that for the single layer roofing. The two layers were mounted with spacers fitted between to maintain a gap of 40 mm.

Five measurement points were marked on the roof upper surface where the temperatures were manually measured with an infrared thermometer (IR800-20D). These five measurements then were used to calculate an average value for the temperature of the roof surface.

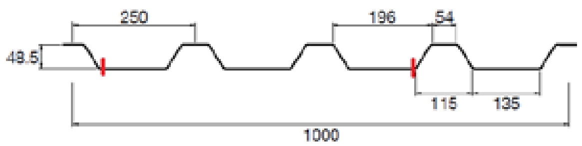
Additionally used were two thermal flow sensors (Heat Flux Plate HFP01; measurement range between +2 000 W/m^2 and -2 000 W/m^2; Thies Clima). The radiation over the roof and heat emissions from the roof underside in the direction of the model interior space were measured using NR Lite silicon net radiometers. The net radiometer measurement range lay between -200 W/m^2 and +1 500 W/m^2. Various temperature sensors (Pt100) recorded the temperature development of the roof upper and undersurfaces as well as in the model interior space. The measurements were recorded every 10 minutes in two data loggers (DL 50; Thies Clima). The measurement period of each trial was a constant 120 minutes whereby the recordings were started 10 minutes after the start of heating.

Fig. 1



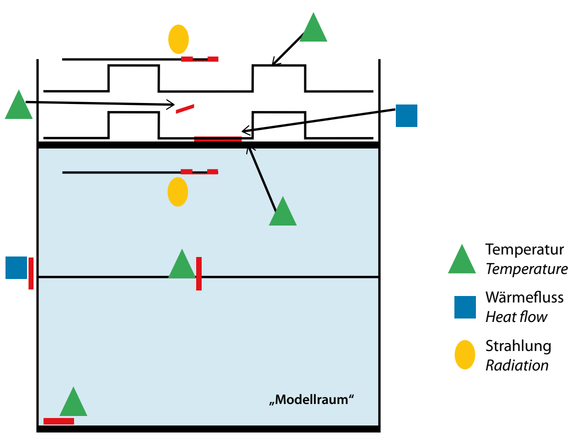
Dimensions of the Sandwich slap [mm]

Fig. 2



Dimensions of the trapezoidal steel profile [mm]

Fig. 3



Position of the sensors during the experiments

Results

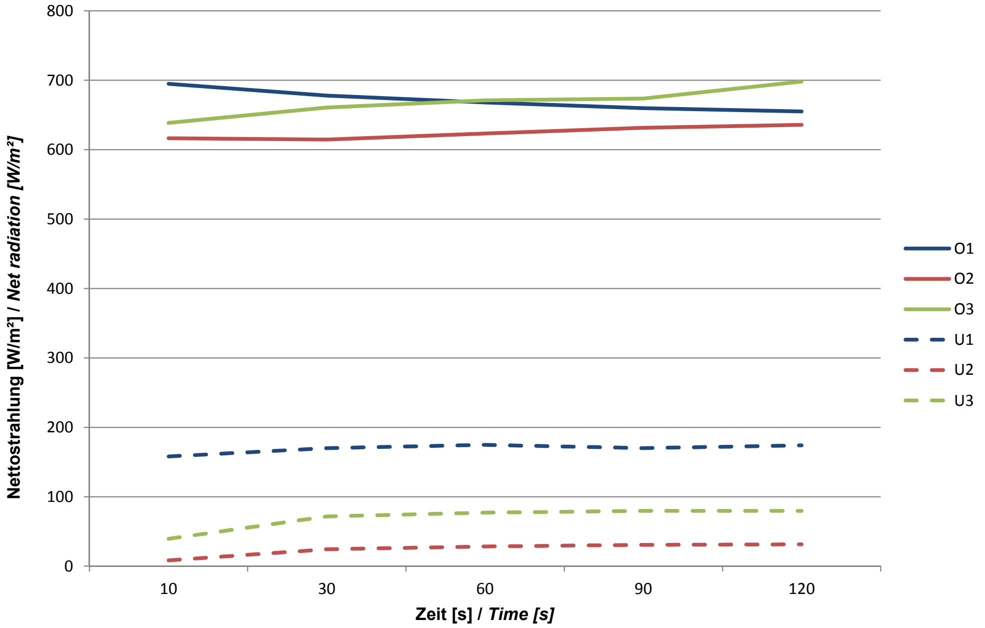
For the following diagrams the sensor measurements per position have been used to calculate an average value. The process in each case starting with the first recordings taken after 10 minutes.

Temperature developments

The upper surface of the sandwich panel heated up most, reaching a temperature of 67.1 °C after two hours whereby a temperature equilibrium was established after one hour. The trapezoidal metal sheeting showed a relatively uniform rise in temperature of the roof upper surface, the rate of increase reducing only after two hours. With the double trapezoidal sheeting the rise in temperature during the first half hour was similar to that of the sandwich panel. Subsequently the temperature rose only slowly up to a maximum of 61.2 °C and, throughout the test period, remained slightly under the temperature of the sandwich roof panel (**Figure 4**).

With regard to the temperatures on the undersurface of the roof materials, the picture was reversed. Through its 30 mm insulation the sandwich panel reached a temperature of 26 °C. As was expected the temperature curve on the undersurface of the trapezoidal sheeting was almost identical with the upper surface. The two temperatures showed on average a difference of only 2 K, the roof undersurface being only slightly cooler. A temperature of 38.7 °C was reached on the undersurface of the double trapezoidal sheeting. While the lower layer was also heated by the very warm upper layer, this did not have the

Fig. 4

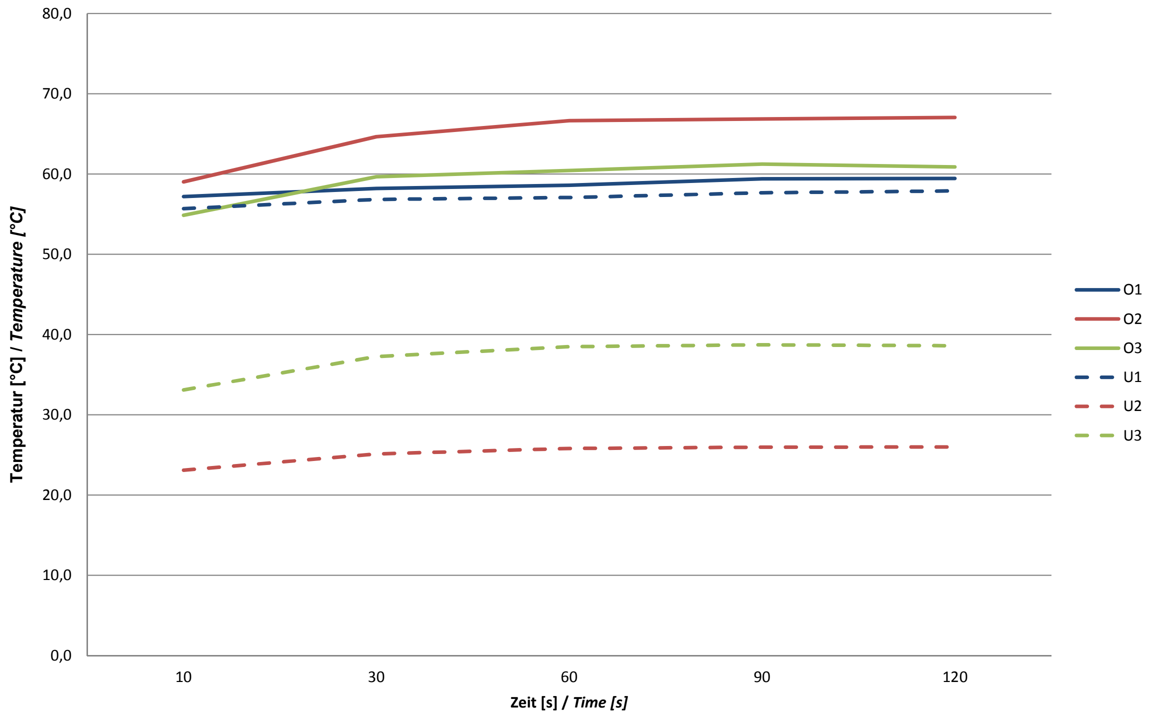


Temperature of the roof
position: O *on the roof*, U *under the roof*; type: 1 *Trapezoidal one layer*; 2 *sandwich slap*; 3 *Trapezoidal double layer*

same effect on the air between the two layers. The temperature lay 1 to 2 K under that of the lower metal sheeting. With the double trapezoidal sheeting, temperature of the lower sheeting itself lay at around 20 K lower than that recorded with the single sheeting.

The net radiation upon the roof surfaces (**Figure 5**) indicated temperature conditions on the upper surfaces. The sandwich panels, where the highest upper surface temperatures were recorded, accordingly received the lowest net radiation as difference between radiation onto the roof and from the roof. With regard to the net radiation under the roof, i.e. heat radiation into the interior space, clear differences between the insulated sandwich roof and the trapezoidal single sheeting roof could be observed. The value for the trapezoidal sheeting lay around

Fig. 5



Netto radiation at the roof
Position: O on the roof, U under the roof; type:1 Trapezoidal one layer, 2 sandwich slap, 3 Trapezoidal double layer

six times higher. And it radiated a relatively constant 150 to 180 W/m^2 downwards. With 80 W/m^2 the double sheeting resulted in a higher value of radiation downwards from the roof than the sandwich panels (31 W/m^2). However, the net radiation was several times less than that recorded from the single trapezoidal sheeting.

These reactions led to differing temperature developments in the model's interior space. While a steady heating-up of the model below-roof space could be observed, the value for the sandwich panel (21.1 °C) lay 4.9 K below the temperature value calculated for the trapezoidal metal sheeting. The measurements for the double trapezoidal metal sheeting (24 °C) lay between the other roofing materials. The difference of 2 K to the single trapezoidal sheeting is relatively low.

Thermal flow in the interior space

The trapezoidal sheeting showed a higher thermal flow value at the beginning of the trial. This was brought about by the very rapid heating-up of the metal sheeting and the emission of heat into the colder model interior space. Subsequently this curve flattened out a little which was partly due to the reducing temperature difference compared to the model interior space. The thermal flow at the underside of the double trapezoidal sheeting was similar to that of the single sheeting with a resultant value that was lower by a factor of three. The procedure was reversed in the case of the sandwich panel where there occurred a slow rise in the thermal flow to a much lower level in total. This was due to the initial very low thermal flow through the insulated material, until the thermal flow reached an almost constant value of 45 W/m^2 with the increasing heating-up of the insulation material and the inner space. The data for thermal flow with both the trapezoidal sheeting variants has to be seen critically because the level of influence on the heat flow through the sensors' own heat resistance was not known.

Conclusions

The relatively small model inner space (only 0.18 m^3) showed itself to be effective for the first measurements of the roofing materials. With ~1 000 W/m² the radiation achieved reflected the average conditions to be expected in Germany. The study showed very clearly that the trapezoidal sheeting offers very unfavourable properties for livestock housing. It gave around 20 % of the radiated heat further into the below-roof interior space. Additionally, the air in the interior was the most strongly heated through the hot roofing of the space. It is not possible to give a final temperature because the length of time of the individual tests was too short for defining the level of interior temperatures that could be expected. As awaited, the insulation with the sandwich panel was best. Surprising in this case was the relatively high upper surface temperature of the roofing material. This was around 8 K over that of the trapezoidal sheeting. Thereby the sandwich panel gave off the largest amount of heat which resulted in the lowest net radiation over the upper surface. With regard to this value the double trapezoidal sheeting lay between the two other materials. The roof upper surface temperature here was also hotter than that of the single trapezoidal sheeting. The radiation downwards was absorbed by the second metal layer of similar construction which itself emitted less than half the heat of the single trapezoidal sheeting. The roof temperatures in the model interior space were very high, however around 20 K cooler than in the case of single trapezoidal sheeting. Thereby there resulted from a thermal point of view not very good, but however still acceptable, characteristics for building simple roofs as protection against the sun, e.g. as shadow roofs out on pasture. These results permit the hope that roofs of double trapezoidal sheeting would be, where possible, voluntary sought out by livestock which would not be the case with single sheeting because of the unfavourable interior microclimate often created.

Literature

[1] Flaig, Bianca (2011): Einfluss der Sonneneinstrahlung auf das Stallklima in Kälberiglus. Bachelorarbeit Uni Hohenheim, Institut für Agrartechnik

[2] Heidenreich, T.; Pache, S. (2009): Mit hellen Dächern den Hitzestress stoppen. Top agrar 7, S. R26–28

[3] IVPU, I. P. (2007): Sommerliches Raumklima im Dachgeschoß: Vergleichende Untersuchungen von Dämmstoffen unter Berücksichtigung instationärer Effekte in einem Modellversuch. Untersuchungsbericht des Forschungsinstitut für Wärmeschutz e.V., München, S. 1–21

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