Thermo-technical properties of floor structures for lying cubicles

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ABSTRACT: A paper dealing with prevailing floor construction types from a thermo-technical point of view. The accent was put on lying cubicles for cows, the floors must be soft, dry, warm and flexible. Attention was paid to analysis of the thermal resistance and thermal absorptive capacity of selected types of flooring. The greatest thermal comfort depends upon the design of floor structured coating materials. A biological floor accretion layer has a positive thermal influence and softens thermal comfort during the animals lying period. A calculation, estimating values of thermal absorptive capacity, shows that the quality and thickness of the structured layer on a covered floor is very important, underlying layers are only affected with thinner designs of a calculated boundary value.

Keywords: cow; floor; lying cubicle; thermal comfort; thermal absorptive capacity

A lying longitude and comfort in relaxation has a primary influence on the total dairy cattle productivity. The lying cow is in direct body contact with the floor during a large part of the day (in positive examples it is 12 to 14 hours per day).

An experiment in 1999 described cows laying in cubicles on 100 mm thick mattresses, 776 minutes daily, on average, and was the best daily time of all ordinary housing systems in use (BRESTENSKÝ et al. 1999). Because of milk quality production there is important an undisturbed resting during lying time. Its thermal comfort is one of the factors affecting lying comfort, and that is why we care about the thermal absorptive capacity of selected types of flooring. Winter thermal discomfort of animals is caused by a structured floor type, which results in a small thermal resistance, but especially high thermal absorptive capacity.

An interactive heat results between the floor and the cow's body as a temperature is measured on the floors surface either by a system of contact thermal sensitive elements or surface temperature measuring, by non-contact measuring equipment, directly after the cow leaves the lying cubicle. Contact temperature drops rapidly during the first and second lying minute. The temperature gradient value from 4 to 15°C is dependent on the structure of the floor (POGRAN, LENDELOVÁ 2002).

At that time, the contacting body part, representing approximately 1.36–1.38 m^2 in area, behaved as a physical entity with constant properties. Then the thermo-regulation process of the animals body starts, the amount of heat flowing from the body's surface and the heat taken by the floor, the surface temperature either increases (so-called warm floors) or drops (cold floors). Finally the new equilibrium thermal state of the body surface temperature drops to the floor surface temperature level (ŠLAJS, HANUŠ 1995).

The floors with low values of thermal absorptive capacity are well accepted by dairy cattle. Contrariwise so called cold floors, with high thermal absorptive capacity values are used for only a short lying time (on concrete floors 2–4 hours daily). Calculating thermal absorptive capacity values is important to assess, how many structured layers will have a demonstrable affect on the thermal absorptive capacity end value, consequently as an equivalent single-layer, double-layer or three-layer floor structure (HALAHYJA et al. 1998).

The aim of this article was to study the floor structures of lying cubicles – with a classic natural or modern artificial bedding – in term of thermo-technical properties of multilayer floors and to clarify the effect of floor structure to dairy thermal comfort in the rest time. In new buildings and reconstructions too, it is important to select from generally used floor constructions those which have the smallest thermal absorptive capacity, high vitality and acceptability for dairy cattle. It is the designing way, how to eliminate a wastage of heat-power flow and to increase the lying comfort.

MATERIALS AND METHODS

Five cubicle flooring materials were tested in winter (2. January–31. March 2003) in the experimental farm of Nitra Research Institute of Animal Production and one flooring material (Styropor mattresses) was tested on Zuberec farm.

The barn in Nitra was divided into two spaces, one part with 18 dairy cows, where 18 elevated cubicles consisting of 150 mm concrete and 150 mm gravel were applied. Eight concrete cubicles from them were covered by mattresses filled by recycled rubber, seven concrete cubicles without mattresses were covered with adjusted dry biological coat thickness of about 20 mm.

There were three concrete cubicles with excrements completely removed and carefully cleaned. The second part of the barn was created of concrete elevated cubicles covered with 65 mm earthenware tiled floor and straw bedding 1 kg/cow/day on the one barn side and with concrete cubicles with straw bedding on the other side of the barn. This observation was carried out with a group of 18 dairy cattle, too.

The sixth type of the flooring was tested in Zuberec farm. There were the similar concrete cubicles with mattresses as in Nitra, but the filling material was crushed rubber-foam.

Thermal measuring was applied using a thermovision camera AGA 570 DEMO and a non-contact thermometer RAYTEK ST 60. For winter observation, we used a non-contact thermometer to measure the surface temperatures (internal air temperatures were +5°C). An experiment was carried out using a circular method handled according to analysis of an accurate thermovision trial from previous experiments (LENDELOVÁ et al. 2002). We selected the most repeated characteristics of the thermal area from drawing camera shooting mostly situated in the back of the recorded thermal shadow-frame. For comparability we carried out all experiments at the same interior temperature, +5°C. The same was done with the specific circle aid, made as one internal file together with 16 lying parts situated between two concentric circles ($\Delta\ r$ = 70 mm). The lying time was noted directly after dairy departure from the cubicle and this template was grounded to the rear part of the leaving warm shadow. Then a temperature resulted, measured in all 17 parts. The average temperature values were evaluated on various lying longitudes from 20 to 60 minutes.

The floor surface temperature may be considered as resultant reaction on structure cubicle floor material defined by the thermal resistance and the thermal absorptive capacity values of equivalent single and double-layer structure technique. The calculating methods corresponded to STN 73 0540-4, part 4: *Calculating technique*. The calculating of an equivalent three-layer structured technique occurs only sporadically with lying cubicle structures. Thermal insulation lying on lower structured layers – under concrete or ceramic – does not affect the improvement of the thermal comfort of the animal when lying. In contrast, the top floor layers with their thermo-technical properties mostly influenced the whole thermal comfort of the resting animal. Therefore we engaged ourselves in research into the properties and design of the thickness of this structured part.

Calculating boundary structure thickness of equivalent single-layers is from the top layer, which substituted whole multi-layer floor structures (a floor layer numbering is done from top to bottom). If the material of top layer is accepted by animals and it is thermo-technically suitable, the thickness would be

$$d_1 \geq \sqrt{3\,\frac{\lambda_1}{c_1\,.\,\rho_1}\,t}$$

where: λ_1 – thermal conductivity coefficient (W/m/K),
c_1 – specific heat capacity (J/kg/K),
ρ_1 – bulk density (kg/m^3),
t – calculating time of body contact with floor construction (t = 600 s).

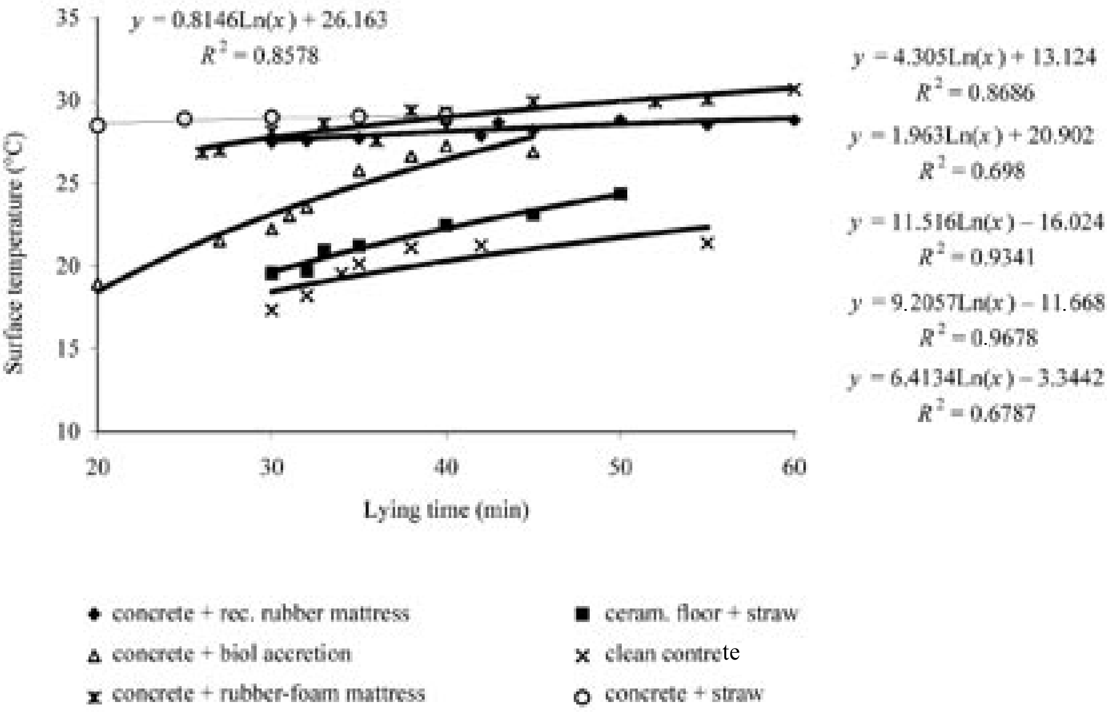

Fig. 1. The results of surface temperatures measuring on various floors

Table 1. The boundary structure thicknesses of equivalent single-layers for various materials and the thermal absorptive capacity for each

Material of the top structured layer	Thermal diffusivity factor $a_1 = \lambda_1/c_1.\rho_1$ (m^2/s)	Minimum top layer thickness $d_1 = \sqrt{3.a_1.t}$ (m)	Thermal absorptive capacity for equivalent single-layer structure $b_1 = \sqrt{c_1.\rho_1.\lambda_1}$ (W/s$^{1/2}$/m^2/K)
Straw	$185.9.10^{-6}$	0.0180	162.3
Recycled rubber mattress	$93.1.10^{-6}$	0.0130	522.3
Foam-rubber mattresses	$167.2.10^{-6}$	0.0170	141.9
Biological accretion	$156.8.10^{-6}$	0.0170	432.8
Sawdust	$199.1.10^{-6}$	0.0189	224.0
Hard wood	$278.1.10^{-6}$	0.0220	795.2
Sand	$327.2.10^{-6}$	0.0243	961.2
Ground	$513.2.10^{-6}$	0.0304	1,186.4
Baked ceramic	$509.3.10^{-6}$	0.0303	1,442.4
Water for mattresses	$135.4.10^{-6}$	0.0156	1,547.2
Concrete	864.10^{-6}	0.0394	1,882.3

Previously the lower layer does not affect the whole floor structure. In designing a thinner top layer, the boundary calculating value of equivalent single-layers is established, it is necessary to consider a negative thermal effect on a second layer by an equivalent double-layer technique. Because of static requirements this second layer generally used to be designed from well steadfast, but less thermo-technical respectable material. Its thermal absorptive capacity used to be 3 to 10 times bigger than the thermal absorptive capacity of a top layer. If the thickness of the second layer does not reach the boundary equivalent double-layer thickness in therms of STN 73 0540-4, it ought to be calculated a third layer influence.

RESULTS

The highest surface floor temperatures were recorded on 100 mm high mattresses, filled with foam-rubber from shoewaste (Styropor). There the temperature increased from a previous temperature of an unoccupied cubicle 7.6°C during 30 minute long lying to a value of 28.3°C on average (Fig. 1).

Similar values were recorded on 100 mm high mattresses filled by recycled tyre rubber and on classic straw bedding, too. Both mattress types and straw bedding were lying on a concrete floor. Unexpectedly high average temperature values, measured on concrete floors without mattresses, were recorded. In our trial it was caused by 10–30 mm layer of biological accretion with well insulated properties (the thermal conductivity $\lambda = 0.172$ W/m/K). Big temperature variations were noted in the very different thickness of this accretion.

If straw bedding is used in lying cubicles, computing the boundary value of equivalent single-layer floor thickness from Table 1 (with the thermal absorptive capacity $b = 162$ W/s$^{1/2}$/m^2/K), will be 18 mm. Additional thickness in increasing straw bedding will not improve

Table 2. Results of the thermal absorptive capacity – with straw top layer

Straw thickness (m)	Straw + concrete floor		Straw + ceramic floor	
	$b = b_1 (1 + K)$ (W/s$^{1/2}$/m^2/K)	R_{s+b} (m^2/K/W)	$b = b_1 (1 + K)$ (W/s$^{1/2}$/m^2/K)	R_{s+k} (m^2/K/W)
0	1,882.00	0.3079	1,442.00	0.5823
0.0025	664.40	0.3436	623.86	0.9394
0.005	494.20	0.3793	456.67	0.6537
0.0075	385.10	0.4150	353.52	0.6894
0.01	306.40	0.4507	290.96	0.7251
0.0125	249.50	0.4865	240.19	0.7609
0.015	208.88	0.5222	203.85	0.7965
0.0175	185.99	0.5579	177.55	0.8323
0.02	172.78	0.5936	162.30	0.8680
0.1	162.30	1.7365	162.30	2.0108
0.2	162.30	3.1650	162.30	3.4394

Table 3. Results of the thermal absorptive capacity – with biological accretion top layer

Biolog. accret. thickness (m)	Biol. acccret. + rubber floor		Biol. acccret. + concr. floor	
	$b = b_1(1 + K)$ (W/s$^{1/2}$/m^2/K)	R_{h+r} (m^2/K/W)	$b = b_1(1 + K)$ (W/s$^{1/2}$/m^2/K)	R_{h+c} (m^2/K/W)
0	522.3	0.3654	1,882.0	0.3079
0.0025	521.3	0.3799	1,176.1	0.3224
0.005	497.6	0.3944	1,021.1	0.3369
0.0075	476.8	0.4090	749.9	0.3515
0.01	461.1	0.4235	636.2	0.3660
0.0125	448.6	0.4381	584.1	0.3805
0.015	441.0	0.4526	488.0	0.3951
0.0175	432.8	0.4671	432.8	0.4096
0.02	432.8	0.4816	432.8	0.4242
0.1	432.8	0.9468	432.8	0.8892
0.2	432.8	1.5282	432.8	1.4706

the whole floor thermal absorptive capacity, but thicknesses under 18 mm down to 0 mm make it rapidly worse (Table 2). By using zero value straw thickness, theoretically, it is the thermal absorptive capacity of the concrete floor b = 1,882 W/s$^{1/2}$/m^2/K (for ceramic floors it is b = 1,442 W/s$^{1/2}$/m^2/K). The thermal absorptive capacity values from 0 to 18 mm were calculated using equivalent double-layer structure techniques. A similar calculation is shown in Table 3, where the state of a non-bedding system was considered. Concrete floors with, or without mattresses, were used.

The thermal resistances, calculated in terms of STN 73 0540-4 are increased with enlarged straw thickness from an initial value of an empty concrete floor R = 0.307 m^2/K/W (for ceramic floor it is R = 0.5823 m^2/K/W) to a value R = 0.558 m^2/K/W (for ceramic floor it is R = 0.8323 m^2/K/W) by boundary value of equivalent single-layer floor thickness. If the straw thickness is 200 mm, the thermal resistance is R = 3.165 m^2/K/W (for ceramic floor it is R = 3.439 m^2/K/W). There are demonstrated boundary values of equivalent double-layer floor thicknesses in Fig. 2, which would not be underestimated, otherwise it would be necessary to include the third-layer influence, too. It is an example that only a wafer-thin layer of bedding material softens the cold floors negative influence.

DISCUSSION

A low temperature in stall buildings, in holding space and in milking parlor – may negatively affect the results of milking by the influence of heat loss or building structures (KARAS et al. 2002). The top coating of the floor determinates the quality of whole floor structure, even though the substructural layers are thermal-insulating (ŠLAJS et al. 1995). We were expecting that the coldest floor from all normally used types is a concrete one. But the lying cubicles surface does not occur in absolutely clean conditions on a non-bedding system of beef-raising and the biological accreation on lying cubicles causes a higher surface temperatures – analogous to values of rubber mattresses and to straw. The layer calculation of biological accretion (in composition of dry manure with cow hair and small parts of food) responding to this fact for smaller thickness than an equivalent boundary value of a single-layer floor one of 17 mm. Its thermal absorptive capacity is consistent to b = 433 W/s$^{1/2}$/m^2/K of rubber mattresses. The biological accretion is a layer of slaty composition created by manure sequential applications on a thin layer by cows hooves on the floor surface. This part of a cubicle underlying after a cow drops the pressure from its body weight (near 4.7 kPa) and cow body temperature (32–39°C).

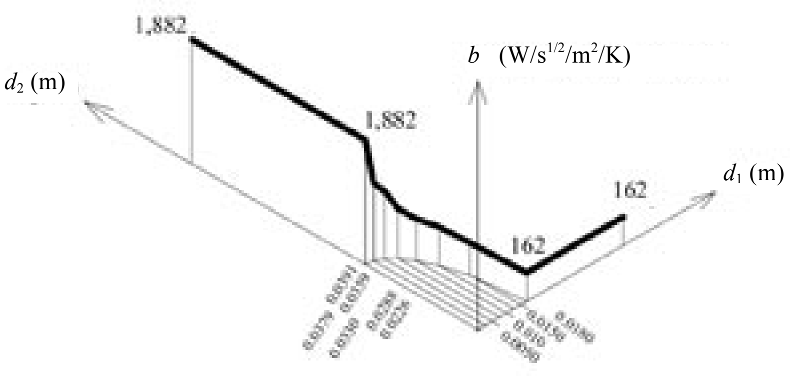

Fig. 2. The thermal absorptive capacity with boundary thicknesses of equivalent double-layer method: d_1 – thickness of straw, d_2 – boundary minimum thickness of concrete

In cubicles used daily, this layer grows little by little and solidifies, but the surface is flattened during lying animals getting up and down. If this accretion forms on rubber mattresses, the floor thermal absorptive capacity does not vary practically – by increasing the layer thickness from 0 to 17 mm. The thermal resistance for this thickness interval increases from $R = 0.356$ to $0.4671\ m^2/K/W$. If the accretion is theoretically 200 mm thick, the thermal absorptive capacity will be $R = 1.528\ m^2/K/W$.

If the accretion is formed directly on to the concrete floor, its resultant thermal absorptive capacity during growing manure thickness from 0 to 17 mm makes it more then four times better. More bulky accretions than the boundary value of equivalent single-layer of manure, will not improve the final thermal absorptive capacity values. But the thermal resistance achieved very similar results to the floor with rubber mattresses covered by dry manure.

CONCLUSIONS

The optimum solution of lying cubicle floors is a structure created by a firmly based course with static and dynamic requirements, with the accent on the design of the top layer. This contact part of a lying cubicle might be created by material with a low thermal absorptive capacity (optimal from 100 to 300, maximum 550 $W/s^{1/2}/m^2/K$). Its thickness would be designed above the minimum boundary value of equivalent single-layer flooring in terms of STN 73 0540-4.

Contrariwise, as we can see from the calculations of minimum boundary values of equivalent double-layer floor structures, using the smallest thickness of thermal-insulation on the top layer, has a negative influence on underlying cold floor streams into the animals body. Therefore the results of thermal absorptive capacity gradually increase to values near the characteristics of cold floors (b = 1,200–1,900 $W/s^{1/2}/m^2/K$). There is some thermal compensation, biological accretion – normally exists in non-bedding beef-raising systems.

The necessary point to consider is hygienic requirements and softness, elasticity and durability floor parameters from final structure design.

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Tepelnotechnické vlastnosti podlahových konštrukcií v ležiskových boxoch pre dojnice

ABSTRAKT: Príspevok sa zaoberá bežnými typmi konštrukcií podláh z hľadiska ich tepelnotechnických vlastností. Dôraz je kladený na ležiskové boxy, ktorých podlaha má byť mäkká, suchá, teplá a pružná. Pozornosť je venovaná rozboru tepelných odporov a tepelných prijímavostí vybraných druhov podláh. Preukázalo sa, že na tepelnú pohodu zvierat vplýva hlavne materiálové riešenie nášľapnej vrstvy. Biologický nános na podlahe má významný tepelný podiel a koriguje tepelnú pohodu zvierat počas ležania. Overené hodnoty tepelných prijímavostí poukazujú na dôležitosť voľby kvality a hrúbky vrchnej – nášľapnej vrstvy lôžka a vplyv čistoty povrchu na tepelnú pohodu zvierat.

Kľúčové slová: kravy; podlaha; ležisko; tepelná pohoda; tepelná prijímavosť podláh

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