XVII^th World Congress of the International Commission of Agricultural Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

BEDDING MATERIALS FOR CATTLE BARNS AND THEIR THERMO-TECHNICAL PROPERTIES IN DIFFERENT CLIMATIC CONDITIONS

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CSBE101021 – Presented at Section II: Farm Buildings, Equipment, Structures and Livestock Environment Conference

ABSTRACT Thermo-technical properties of organic materials (straw, sawdust, separated slurry with thickness of 200 mm on concrete base) in comparison to rubber mats and rubber foam mattresses used for bedding of cubicles for dairy cows were evaluated. Thermal resistance and thermal effusivity were calculated according to official technical standards. Coefficient of thermal conductivity needed for these calculations were obtained in real conditions of experimental farms. Thermal resistance of straw varied from 0.966 to 2.914 $m^2.K.W^{-1}$, wooden sawdust from 0.688 to 1.781 $m^2.K.W^{-1}$, separated slurry from 0.908 to 1.274 $m^2.K.W^{-1}$, and rubber mattresses and mats from 0.76 to 1.47 $m^2.K.W^{-1}$. Thermal effusivity of straw ranged from 162.34 to 423.63 $W.s.^{1/2}m^{-2}K^{-1}$, wooden sawdust from 333.5 to 773.52 $W.s.^{1/2}m^{-2}K^{-1}$, separated slurry from 308.97 to 469.36 $W.s.^{1/2}m^{-2}K^{-1}$. Data were collected in summer as well as in winter conditions and both with dry and wet organic materials.

Keywords: cubicles, bedding, thermal resistance, thermal effusivity

INTRODUCTION Proper flooring management and free-stall design is critical for effective control of production parameters, cattle health, longevity and comfort. Many studies have investigated the bedding preferences of dairy cows by comparing different types of floor structures (Palmer et al., 2003; Wechsler et al., 2000; Tucker et al. , 2003). Results of similar experiments indicate that cows prefer stalls with softer, elastic, dry and slip resistant floors. A variety of flooring surfaces are used on dairy farms, but not much is known about their impact on thermal comfort of cattle. Dairy cow free stalls have traditionally been bedded with different organic materials or synthetic products available locally. Bedding material has ranged from straw, wood chips, dolomite limestone and sawdust to separated manure solids. Organic bedding materials in dry conditions are characterized with a big absorbability and low thermal conductivity. However, most organic bedding materials support bacterial growth (Russell et al., 2002). Control of bacterial growth means depriving bacteria of substrate for their growth: moisture, organic matter, and proper temperature and pH. Keeping litter in dry conditions and lower temperature results also in decreasing ammonia emissions from this source (Knížatová et al., 2007).These properties also affect thermo-technical magnitudes (Chmúrny, 2003). Thermal comfort during lying is caused by a structure of bed characterised by thermal resistance and thermal effusivity. Thermo-technical condition in stable creates a nonstationary process caused by climatic conditions and farm management (Pogran, 2000). To avoid heat loss from building in winter periods thermal resistance should be as high as possible. On the other hand, thermal effusivity should be as low as possible, to prevent heat conduction from animal body while lying. The aim of this work was to evaluate the thermo-technical properties of organic materials (straw, sawdust, separated slurry with thickness of 200 mm on concrete base) in comparison to rubber mats and rubber foam mattresses used for bedding in cubicles for dairy cows.

MATERIAL AND METHODS Thermo-technical properties of five different cubicle floors of bed structures were tested in Slovak farms. Three cubicles with deepened concrete stall base were covered by 200 mm layer of straw, sawdust and separated manure, respectively (fig. 1) and two cubicles with elevated concrete stall base covered by rubber mats and rubber foam mattresses (fig. 2), respectively, were used.

Thermal resistance and thermal effusivity were calculated according to official technical standards. Data needed for the calculations were obtained in real conditions of experimental farms, both in summer and winter conditions and both with dry and wet organic materials.

Thermal resistance was calculated as follows:

$$R = \sum_{j=1}^{n} R_j = \sum_{j=1}^{n} \frac{d_j}{\lambda_j} = \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + ... + \frac{d_n}{\lambda_n} \text{, m}^2\text{.K.W}^{-1} \quad (1)$$

where R_j – thermal resistance of „j“ floor layer, $m^2.K.W^{-1}$

d_j – thickness of „j“ layer, m

λ_j – thermal conductivity coefficient „j“ layer, $W.m^{-1}.K^{-1}$

Thermal effusivity for single-layer equivalent structure of cubicle bed was calculated as follows:

$$b = \sqrt{\lambda.c.\rho} \text{, W.s}^{1/2}\text{.m}^{-2}\text{.K}^{-1} \quad (2)$$

where c - specific thermal capacity, $J.kg^{-1}.K^{-1}$

ρ - bulk density, $kg.m^{-3}$

Thermal effusivity for two layer equivalent structure of cubicle bed was calculated as follows:

$$b = b_1(1 + K_{1,2}) \text{, W.s}^{1/2}\text{.m}^{-2}\text{.K}^{-1} \quad (3)$$

where

$$K_{1,2} = f\left(\frac{b_2}{b_1}, \frac{d_1^2}{a_1.\tau}\right), \quad (4)$$

where

b_1 - is thermal effusivity of first floor layer in $W.s^{1/2}.m^{-2}.K^{-1}$

b_2 - is thermal effusivity of second floor layer in $W.s^{1/2}.m^{-2}.K^{-1}$

$$b_1 = \sqrt{\lambda_1.c_1.\rho_1} \text{ , } b_2 = \sqrt{\lambda_2.c_2.\rho_2} \quad (5)$$

"Boundary" structure thickness was calculated as follows:

$$d_{1b} = 42{,}4.\sqrt{a_1}\ , \qquad \text{m} \tag{6}$$

where

a_1 – is thermal diffusivity factor

$$a_1 = \frac{\lambda_1}{c_1.\rho_1}\ , \qquad \text{m}^2.\text{s}^{-1} \tag{7}$$

Comparative criterion is relation of

$$d_1 > d_{1m}, \tag{8}$$

where d_1 – is thickness of first – top floor layer, *m*

and $\frac{d_1^2}{a_1 \cdot \tau} \geq 3$ for single-layer equivalent floor structure (9)

for time τ = 600 seconds and *two-layer equivalent* floor structure must be truthful:

$$\frac{d_1^2}{a_1.\tau} + \frac{d_2^2}{a_2.\tau} \geq 3 \tag{10}$$

for *three-layer equivalent floor structure* must be founded, if

$$\frac{d_1^2}{a_1.\tau} + \frac{d_2^2}{a_2.\tau} + \frac{d_3^2}{a_3.\tau} \geq 3 \tag{11}$$

Then formula for thermal effusivity of *equivalent three-layer floor structure* is:

$$b = b_1(1+K_{1,2,3}) \tag{12}$$

where $K_{1,2,3} = f\left(\frac{b_{2,3}}{b_1}, \frac{d_1^2}{a_1.\tau}\right)$ (13)

and $b_{2,3} = b_2(1+K_{2,3})$ (14)

where $K_{2,3}$ is computed from function

$$K_{2,3} = f\left(\frac{b_3}{b_{21}}, \frac{d_2^2}{a_2.\tau}\right) \tag{15}$$

and $b_3 = \sqrt{\lambda_3.c_3.\rho_3}$ (16)

Note: More than three equivalent layers floor is not common in animal housing practise.

Calculation of quantity $K_{1,2}$, $K_{2,3}$ a $K_{1,2,3}$ *is* analytics was done according to

$$K_{x,y} = 2.\sum_{n=1}^{\infty}\left(\frac{x-1}{x+1}\right)^{n}.e^{\left(-n^{2}.y\right)} \tag{17}$$

where *"x"* – is first parameter; *"y"* – is second parameter in formula 13, 15 (Chmúrny, 2003)

RESULTS AND DISCUSSION Thermo-technical parameters varied according to climatic conditions and farm management (Tables 1 - 4). Very good results were obtained for all dry organic materials. They had very good absorption and cushioning. Average value of thermal resistance (R_{dry}) varied from 1.274 $m^2.K.W^{-1}$ (for separated slurry) to 2.914 $m^2.K.W^{-1}$ (for dry straw), and thermal conductivity coefficient (λ_{dry}) from 0.06 to 0.16 $W.m^{-1}K^{-1}$, respectively. The organic beddings tested in wet conditions recorded their thermal resistance (R_{wet}) with in the range 0.688 to 0.966 $m^2.K.W^{-1}$, and thermal conductivity coefficient (λ_{wet}) from 0.23 to 0.32 $W.m^{-1}K^{-1}$.

The rubber mats and mattresses had lower thermal resistance (0.76 to 1.469 m^2KW^{-1}) than dry organic materials. However, it was much higher and better than concrete base without any bedding (0.12 $m^2.K.W^{-1}$).

Results of thermal effusivity had similar tendency as thermal resistance data. Again, dry straw (162.34 $W.s^{1/2}.m^{-2}.K^{-1}$) was the best among organic materials. The thermal effusivity of rubber foam mattresses was little bit better than dry straw (144.35 $W.s^{1/2}.m^{-2}.K^{-1}$). All investigated materials had manifolds better thermal effusivity than concrete not covered by any bedding (from 144.35 to 773.52 $W.s^{1/2}.m^{-2}.K^{-1}$, in comparison to 1880 $W.s^{1/2}.m^{-2}.K^{-1}$). Thermal comfort on synthetic materials (rubber mats and mattresses) could be improved by spreading of a small amount of organic material (Figure 3).

Thermal resistance values increased with the increase in thickness of top layer (Tables 1 & 3, Figure 4). However, from the thermal comfort point of view values of thermal resistance are important only from higher thickness of layer (more than 150 mm). Higher values of thermal resistance of beds for animals also positively influence entire the thermal balance of the housing building.

On the other hand, total value of thermal effusivity rapidly improved by addition of litter material (straw, sawdust or separated manure solids) only up to the so called boundary thickness value of top layer (Tables 2 & 4, Figure 4). Additional supplement of organic litter material had only slight almost no influence. A boundary equivalent thickness has a crucial role. It depends on type of material and thermal diffusivity factor (Table 5).

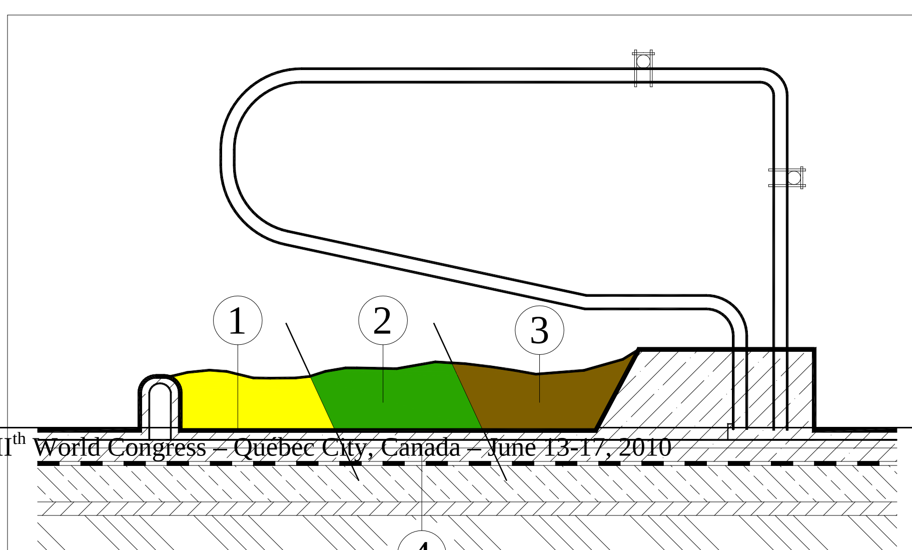

Figure 1. Deepened stall base cubicle bedded by organic materials
1 – straw, 2 – sawdust, 3 – separated slurry, 4 - concrete

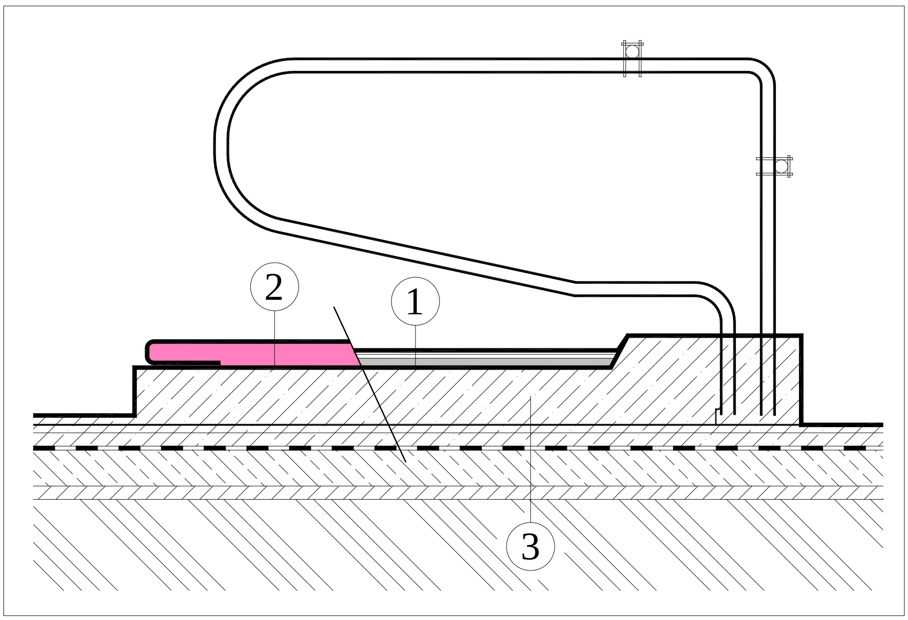

Figure 2. Elevated stall base cubicle covered by synthetic materials
1 – rubber mats (35 mm of insulation flexible recycled material, 15 mm of rubber covering),
2 – rubber foam mattress (100 mm of rubber crushed recycled or foam material with special cover)
3 – concrete

Table 1. Thermal resistance of different types of bedding in deepened concrete stall base cubicles

Thickness of bedding, m	**R_{dry} - Thermal resistance** of lying concrete structure with different thickness of bedding **in dry conditions,** $m^2.K.W^{-1}$			**R_{wet} - Thermal resistance** of lying concrete structure with different thickness of bedding **in wet conditions,** $m^2.K.W^{-1}$		
	Chopped straw	Wooden sawdust	Separated slurry	Chopped straw	Wooden sawdust	Separated slurry
0*	0.057	0.057	0.057	0.057	0.057	0.057
0.0025	0.093	0.079	0.069	0.068	0.065	0.068
0.005	0.128	0.100	0.084	0.080	0.073	0.078
0.0075	0.164	0.122	0.100	0.091	0.081	0.089
0.01	0.200	0.143	0.115	0.102	0.089	0.100

*The values of Thermal resistance “R” in first row represent a concrete floor without bedding; R remains the same (in case of 100 mm concrete thickness above waterproof insulation). Thermal resistance of structure layers under waterproof insulation is unthinkable by Slovak technical standards.

Table 2. Thermal effusivity of different types of bedding in deepened concrete stall base cubicles

Thickness of bedding, m	**b_{dry} - Thermal effusivity** of lying concrete structure with different thickness of bedding **in dry conditions,** $W.s^{1/2}.m^{-2}.K^{-1}$			**b_{wet} - Thermal efussivity** of lying concrete structure with different thickness of bedding **in wet conditions**, $W.s^{1/2}.m^{-2}.K^{-1}$		
	Chopped straw	Wooden sawdust	Separated slurry	Chopped straw	Wooden sawdust	Separated slurry
0**	1882,02	1882,02	1882,02	1882,02	1882,02	1882,02
0.0025	602,54	991,13	1011,57	1379,98	1589,60	1331,47
0.005	470,49	744,18	868,82	1065,56	1375,34	1138,46
0.0075	353,67	561,24	712,42	886,57	1170,43	936,76
0.010	276,61	450,99	585,62	741,13	1016,53	789,23
0.015	196,64	353,98	428,72	558,35	841,93	606,45
0.020	169,16	335,30	351,18	468,89	785,45	527,92
0.050	162.34	333.50	308.97	423.63	773,53	499.26
0.100	162.34	333.50	308.97	423.63	773.53	499.26
0.150	162.34	333.50	308.97	423.63	773.53	499.26
0.200	162.34	333.50	308.97	423.63	773.53	499.26

** The values of Thermal effusivity “b” in first row represent a concrete floor without bedding.

Table 3. Thermal resistance of different types of additional bedding materials on elevated stall base cubicles with rubber mats

Thickness of bedding, m	**R_{dry} - Thermal resistance** of lying concrete structure with rubber insulated mats and different thickness of bedding **in dry conditions,** $m^2.K.W^{-1}$			**R_{wet} - Thermal resistance** of lying concrete structure with rubber insulated mats and different thickness of bedding **in wet conditions,** $m^2.K.W^{-1}$		
	Chopped straw	Wooden sawdust	Separated slurry	Chopped straw	Wooden sawdust	Separated slurry
0*	0.734	0.734	0.734	0.734	0.734	0.734
0.0025	0.771	0.756	0.749	0.745	0.742	0.745
0.005	0.808	0.771	0.764	0.757	0.750	0.755
0.0075	0.844	0.799	0.780	0.768	0.758	0.766
0.01	0.881	0.820	0.795	0.779	0.766	0.777
0.015	0.955	0.863	0.825	0.802	0.781	0.798

* R remains the same as without bedding (calculated only for the structure of 100 mm concrete thickness above waterproof insulation, 35 mm of insulation and 15 mm of rubber covering). Thermal resistance of structure layers under waterproof insulation is unthinkable by Slovak technical standards.

Table 4. Thermal effusivity of different types of additional bedding materials on elevated stall base cubicles with rubber mats

Thickness of bedding, m	**b_{dry} - Thermal effusivity** of lying concrete structure with rubber insulated mats and different thickness of bedding **in dry conditions,** $W.s^{1/2}.m^{-2}.K^{-1}$			**b_{wet} - Thermal effusivity** of lying concrete structure with rubber insulated mats and different thickness of bedding **in wet conditions**, $W.s^{1/2}.m^{-2}.K^{-1}$		
	Chopped straw	Wooden sawdust	Separated slurry	Chopped straw	Wooden sawdust	Separated slurry
0**	522.10	522.10	522.10	522.10	522.10	522.10
0.0025	437,34	493,41	500,26	516,99	531,06	516,49
0.005	340.17	444.12	458,33	503.23	559,64	501.80
0.0075	270,69	402,18	419,36	487,89	607,52	492,75
0.010	234.21	370.60	381,45	471.54	663.45	468.79
0.015	185.31	339,97	329.54	446.04	744.05	444,88
0.020	167.56	333.42	315.57	433.71	768,11	433.38
0.050	162.34	333.50	308,97	423.63	773.52	429.26
0.100	162.34	333.50	308,97	423.63	773.52	429.26

** The values of thermal effusivity "b" in the first row represent a high concrete lying floor with insulated mats without bedding.

Table 5. Boundary thickness of different materials for cow lying area

Top layer material	Thermal diffusivity factor of top layer $a_1 = \frac{\lambda_1}{c_1.\rho_1}$, $m^2.s^{-1}$	Boundary thickness of one-layer equivalent floor structure $d_{1b} = 42,4.\sqrt{a_1}$, m
Chopped straw - dry	$1.594.10^{-7}$	0.0188
Chopped straw - wet	$2.697.10^{-7}$	0.0220
Wooden sawdust - dry	$1.210 .10^{-7}$	0.0147
Wooden sawdust - wet	$1.679.10^{-7}$	0.0174
Separated slurry - dry	$2.853.10^{-7}$	0.0226
Separated slurry - wet	$2.216.10^{-7}$	0.0199
Hard rubber	$0.940.10^{-7}$	0.0130

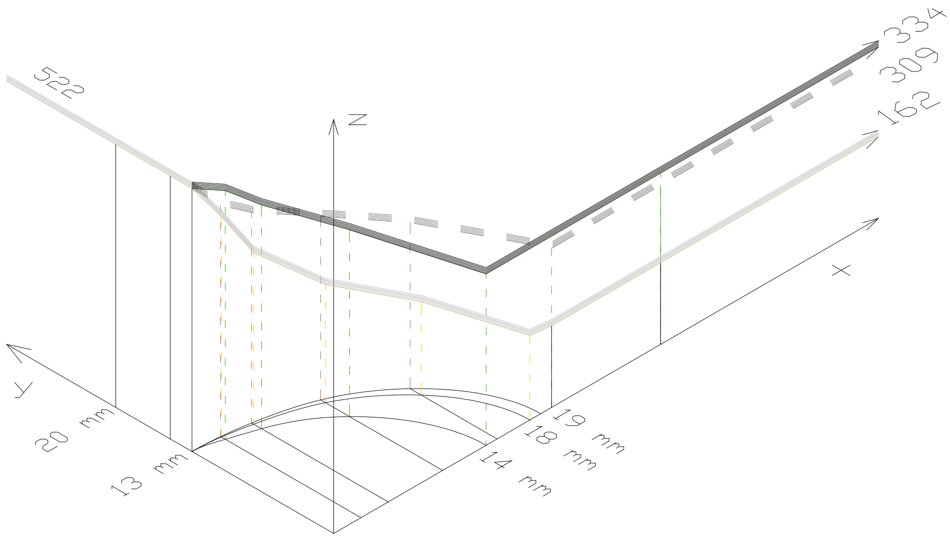

Figure 3. Changes in thermal effusivity by adding straw (light grey), sawdust (black), or separated slurry (dark grey - dashed) on rubber surface in dry conditions.
x – thickness of first layer floor structure with organic bedding
y – thickness of second layer structure from rubber
z – thermal effusivity, Ws $^{1/2}$ m^{-2} K $^{-1}$

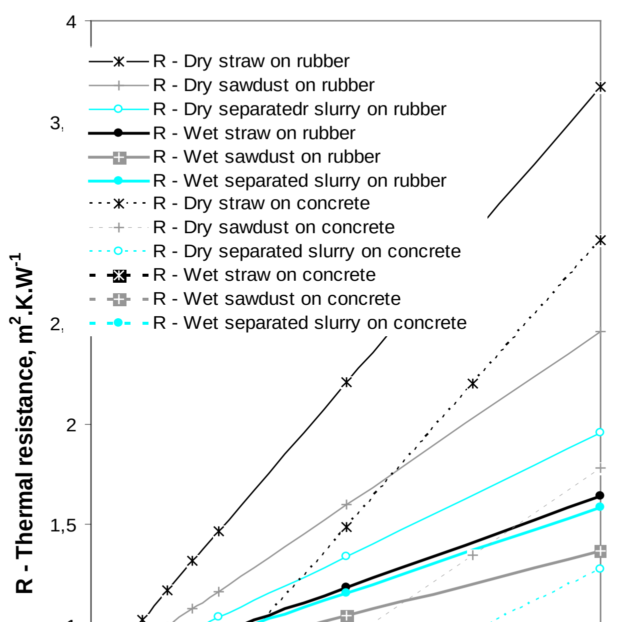

Figure 4. Effect of additional supplement of organic litter material on thermo-technical properties of cubicle floor

CONCLUSIONS

- All types of investigated bedding materials improved thermo-technical properties of cubicle bed both from their thermal resistance and thermal effusivity point of view.
- Better thermal comfort can be expected for organic materials, straw first of all, however, only in drier weather conditions.
- Rubber foam mattresses have thermo-technical properties comparable to straw. Thermal comfort on synthetic materials (mats and mattresses) could be improved by spreading small amount of organic material. It can also absorb moisture and increase cleanliness and hygiene of cubicle bed.
- Cubicles with separated manure bed create good comfort for lying animals comparable to straw and sawdust bedding. From a thermo-technical point of view,

separated manure solids bedding is comparable to rubber foam, and also to straw, but only to a wet straw. The question is, whether the hygiene of “manure” bed is satisfactory. To reach an objective evaluation of the above mentioned problems a new project has been undertaken recently.

Acknowledgements. Portions of this work were supported by project VEGA 1/0771/09. Participation in the XVIIth World Congress of the CIGR was supported by the project of EU Structural Funds “ITEPAG” no.: 26220220014.

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