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Impact of climatic conditions on dairy cows kept in open buildings

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Abstract
The aim of this study was to assess whether dairy cows kept in open buildings are able to cope with the range of climatic conditions which may occur in such buildings in central Europe. On each of four commercial farms, ten lactating cows were observed over a total of five weeks in winter, spring and summer. For each cow, both behavioural and physiological parameters were recorded simultaneously. In addition, air temperature (range -13.8 to 28.7°C) and relative air humidity (range 25.8 to 98.8%) were measured continuously, and a temperature humidity index (THI) was calculated.
THI had significant effects (General Linear Model, $p < 0.0001$) on skin and body surface temperature during both night and day. With regard to rectal temperature, duration of lying and cortisol concentration in the milk, there were significant effects ($p < 0.0001$) of THI for the day but not for the night time. Heart rate and frequency of lying did not covary significantly with THI. For most physiological and behavioural parameters, there were also significant differences between farms ($p < 0.05$) and significant interactions between THI and farm ($p < 0.05$). In conclusion, the results indicate that within the measured range of climatic conditions the cows were hardly exposed to severe cold or heat stress.

Introduction
Traditionally, dairy cows in northern and central Europe were kept in tie-stalls and in closed stables. Nowadays, however, loose housing systems are preferred to reduce labour input with increasing herd sizes as well as to meet animal welfare requirements. In order to minimise investment costs for new or reconstructed stables these loose housing systems are often built in open-fronted buildings or even in buildings open to all sides. As a consequence, the cows are exposed to a wide range of climatic conditions which, in part, can become extreme. This raises the question of whether dairy cows are able to cope with these housing conditions.
The aim of the present study was to examine the influence of a wide range of climatic conditions ranging from cold in winter to heat in summer on physiological and behavioural parameters in lactating cows kept on Swiss farms. Moreover, we measured a variety of parameters (skin temperature, body surface temperature, rectal temperature, lying behaviour, heart rate and milk cortisol concentration) simultaneously in the same individuals.

Material and methods
Housing systems, animals and observation periods
The study was carried out on four Swiss farms (A, B, C, D) with loose housing systems for dairy cows located between 400 and 570 m above sea level (Zähner et al., 2004). The cows were housed all year round. On two farms (A, B) they were kept in stables with an unstructured lying area with straw bedding whereas on the other two farms they were housed in cubicle systems with either straw bedding (C) or soft lying mats (D). The soft mats were five years old, 10 cm thick and a thin layer of straw bedding was used on top of them. The stables had one (open-front houses: A, D) or

four (open houses: B, C) open sides, resulting in indoor climatic conditions similar to the outdoor conditions (Zähner, 2001). On all farms, the cows also had free access to an outdoor area (concrete or partially slatted floor; 5·9, 4·6, 5·9 and 3·5 m^2 per animal, respectively, on farm A, B, C and D). The herd size on the four farms was 22, 23, 33, and 18 cows with an average milk yield of 6500 kg, 5000 kg, 6000 kg and 7300 kg per lactation. The cows were of different breeds (farms A and C: Brown Swiss; farm B: Brown Swiss as well as crossings between Red Holstein and Swiss Simmental; farm D: Holstein-Friesian).

On each farm, data were collected over four consecutive days each during two weeks in winter (December 1998 to February 1999), one week in spring (April 1999), and two weeks in summer (June to August 1999). The aim of this design was to cover a wide range of climatic conditions including extreme values in winter and summer.

On each farm, ten lactating cows were selected randomly as focal animals for data collection. Whenever possible, the same animals were observed over all observation periods. In some cases, however, dry cows had to be replaced by new randomly selected lactating individuals.

Climatic conditions

Climatic conditions were quantified by the use of a weather station positioned at a distance of 40 to 50 m from the stable. During the observation periods, air temperature (in °C) and relative air humidity were recorded automatically every minute. From these values a temperature humidity index (THI; Hahn and Mader, 1997) was calculated using the following formula:

THI = 0·8 x Temperature + Relative air humidity x (Temperature – 14·4) + 46·4

The THI is used as an indicator of climatic stress because, at a given temperature, thermoregulation is more difficult with increasing relative air humidity. As a consequence, relative air humidity is multiplied with temperature in the THI used. For the analysis, mean values of THI were calculated for each farm separately for each day of observation for the night (21:00 to 05:00 h) and the day time (05:00 to 21:00 h).

Physiological and behavioural parameters

A variety of physiological and behavioural parameters were quantified for each focal animal. Skin temperature was recorded automatically every minute by means of a temperature sensor fitted in a belt mounted around the front part of the cow's body, just behind the forelegs. In this belt, the temperature sensor was positioned in the upper quarter of the body. Body surface temperature on the leg (metatarsus), the thigh and the udder was measured by means of infrared thermography on two days per week of observation, twice a day after milking at about 08:00 and 17:00 h. The hair was not clipped at these parts of the body for the measurement of the surface temperature. Rectal temperature was measured on all observation days, also twice a day after milking at about 08:00 and 17:00 h.

The duration and the frequency of lying behaviour was recorded automatically using a pneumatically operated resting sensor (Hauser et al., 1999) fitted in the belt mounted behind the forelegs. Heart rate was measured continuously and registered every minute with the Polar Horse Trainer also fitted in the belt.

Finally, milk samples (10 ml) were taken directly after the foremilking from all teats twice on each day of observation at about 08:00 and 17:00 h. Concentrations of cortisol were analysed from the milk samples using a radio-immunoassay.

Statistical analysis

For the analysis, we calculated mean values across the subjects of a given farm of the skin temperature, the duration of lying behaviour, the frequency of lying down and the heart rate for each observation day for the night and for the day time. Similarly, mean values of the body surface temperature, the rectal temperature and the cortisol concentration in the milk samples were calculated across the subjects of a given farm for each observation day from the morning and the afternoon data. Thus, the total number of data included in the statistical analysis was n = 80 for the data ob-

tained at night and day time respectively (data were collected from each of the 4 farms on 2 x 4 days in winter and in summer respectively, and on 1 x 4 days in spring; n = 20 days of observation x 4 farms = 80). However, since the body surface temperature was measured only on 2 days per week of observation, for this measurement the number of data was n = 40.
The effects of the THI and the farms on the dependent variables we tested by using a General Linear Model (GLM, Type III). The THI was included in the model as a covariate. The farms were included as a fixed factor in order to test for differences between farms and in order to correct for the effect of farm by including the interactions between farm and THI. This resulted in the model 'dependent variable = THI + farm + THIxfarm'. In order to test for differences between the values obtained in the morning and the afternoon (i.e. either values obtained at 08:00 and 17:00 h, or during the day and during the night) we used a paired samples t-test. Differences between farms regarding the THI were tested separately for each season using oneway ANOVA with farms as factor and the daily mean values of the THI as dependent variable. In order to quantify the strength of the relationship between the THI and the body surface temperature measured at the different body parts, a regression analysis was done. The slope (m) of the linear regression curve characterizes how strong the body surface temperature of the different body parts was related to the THI. The coefficient of regression (b) indicates how well the data were fitted to the linear regression. All mean values are given with the standard deviation (mean ± sd). All statistics were done with SPSS for windows (Version 11.0.1).

Results

Climatic conditions

Table 1 gives an overview of the climatic conditions on the four farms. The air temperature measured ranged from -13·8 °C (farm B in winter at night) to 28·7°C (farm A in summer at day time). Mean values of temperature at night in winter varied between -5·5°C (farm B) and -0·9°C (farm A). In summer, mean temperature at day time ranged from 16·2°C (farm D) to 19·6°C (farm B). Relative air humidity varied between 26% (farm D in summer at day time) and 99% (farm A, B, and D in summer), and mean humidity values ranged from 67% (farm D in summer at day time) to 95% (farm C in summer at night time).
In winter and in spring the THI differed significantly between farms (both $P < 0·05$), but not in summer ($P > 0·05$).

Table 1: Mean (min/max) values of air temperature and relative air humidity on the four farms during winter, spring, and summer at night and day time

		farm							
		A		**B**		**C**		**D**	
Temperature [°C]									
Winter	night	-0·9	(-5·7/6·9)	-5·5	(-13·8/0·0)	-1·1	(-5·1/2·7)	-3·5	(-9·8/3·2)
	day	-0·2	(-6·0/8·6)	-3·9	(-11·7/0·7)	0·3	(-5·3/8·1)	-2·8	(-10·7/4·4)
Spring	night	9·4	(6·1/15·3)	4·6	(-2·2/8·2)	7·1	(3·3/15·3)	2·1	(-1·8/8·2)
	day	13·3	(5·8/20·0)	7·0	(-1·7/14·0)	10·0	(3·5/19·9)	3·4	(-1·7/10·6)
Summer	night	14·2	(9·2/21·8)	15·7	(10·1/21·3)	13·3	(8·9/19·2)	11·9	(4·0/20·3)
	day	18·8	(9·6/28·7)	19·6	(10·3/27·5)	16·9	(8·8/24·8)	16·2	(4·4/25·5)
Humidity [%]									
Winter	night	85	(59/97)	90	(71/98)	90	(65/98)	87	(68/98)
	day	83	(46/97)	83	(56/98)	87	(64/98)	80	(55/95)
Spring	night	86	(60/98)	89	(71/98)	84	(51/98)	86	(54/98)
	day	68	(36/98)	78	(43/98)	73	(38/97)	78	(40/98)
Summer	night	91	(64/99)	86	(60/98)	95	(66/99)	84	(54/99)
	day	73	(39/99)	73	(39/98)	79	(36/99)	67	(26/99)

Skin temperature

During the night the skin temperature (29·0 ± 2·9 °C) was significantly lower than the skin temperature measured during the day (29·8 ± 3·2 °C, P < 0·0001). During the day as well as during the night the skin temperature decreased significantly with a decreasing THI (both P < 0·0001, Figure 1a, b). In addition, the skin temperature differed significantly between farms for both night and day values (night: P < 0·01; day: P < 0·05). The significant interaction between THI and farm (night: P < 0·0001; day: P < 0·05) indicates, that this difference in skin temperature was affected by the different climatic conditions on the farms.

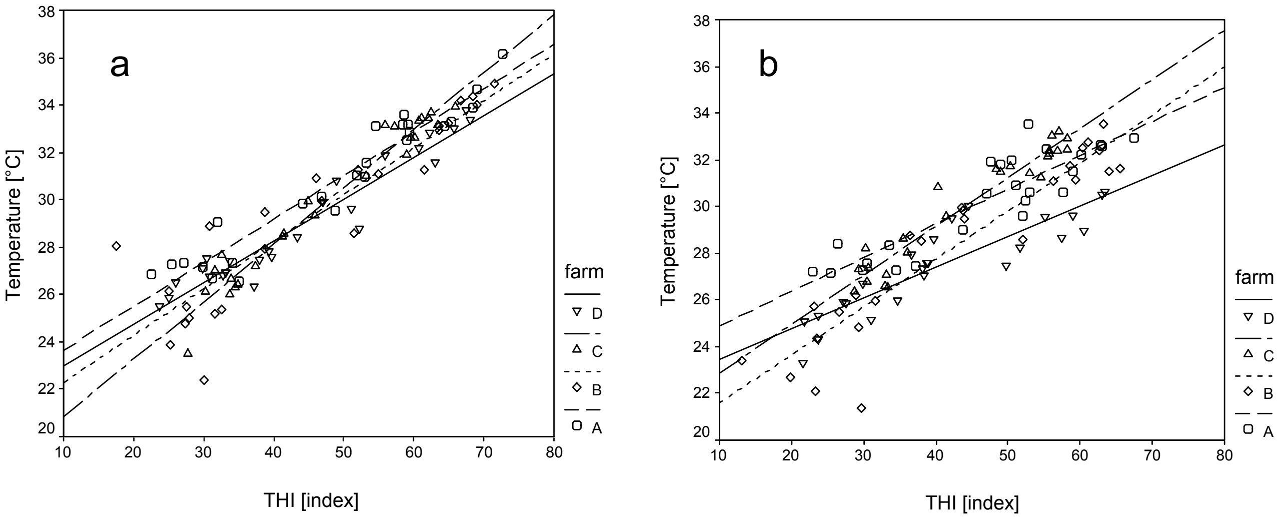

Figure 1: Relationship between the skin temperature and the temperature humidity index (THI) (a) during the day and (b) during the night.

Body surface temperature

The body surface temperature measured by means of infrared thermography was lowest on the skin of the leg (17·4 ± 8·6 °C), followed by the thigh (22·4 ± 6·8 °C) and the udder (27·5 ± 4·2 °C) (Figure 2a). Surface temperature measured at 08:00 h decreased significantly with a decreasing THI in each part of the body (all P < 0·0001). The temperature measured on the leg was most sensitive to a decrease in THI (m = 0·462, b = 0·933), followed by the temperature on the thigh (m = 0·365, b = 0·931) and the udder (m = 0·218, b = 0·913). In addition, the surface temperature measured at 08:00 h differed significantly between farms in each part of the body (leg: P < 0·01; thigh: P < 0·05; udder: P < 0·01). For the values measured on the leg and on the udder there was also a significant interaction between THI and farm (both P < 0·05).

In the measurements at 17:00 h, body surface temperature also decreased significantly with a decreasing THI in each part of the body (all P < 0·0001) (Figure 2b). Again, the relationship between the decreases in surface temperature and THI was strongest on the leg (m = 0·555, b = 0·982), followed by the thigh (m = 0·419, b = 0·963) and the udder (m = 0·261, b = 0·959). In comparison with the values obtained at 08:00 h, the higher values of the slopes indicate that the decrease of body surface temperature was stronger at 17:00 h. Between farms the differences were significant with regard to the temperatures measured on the thigh (P < 0·01) and on the udder (P < 0·05). With those two parts of the body, we also found significant interactions between THI and farm (both P < 0·05).

Rectal temperature

Although the differences were rather small, the rectal temperature measured at 08:00 h (38·36 ± 0·14 °C) was significantly lower than the temperature at 17:00 h (38·55 ± 0·14 °C) (P < 0·0001). The rectal temperatures measured at 08:00 h were not significantly affected by THI, but differed significantly between farms (P < 0·001). In addition, there was a significant interaction between THI and farm (P < 0·05). At 17:00 h rectal temperature increased significantly with an increasing

THI (P < 0·0001). The difference between farms and the interaction between farm and THI were also significant (both P < 0·0001).

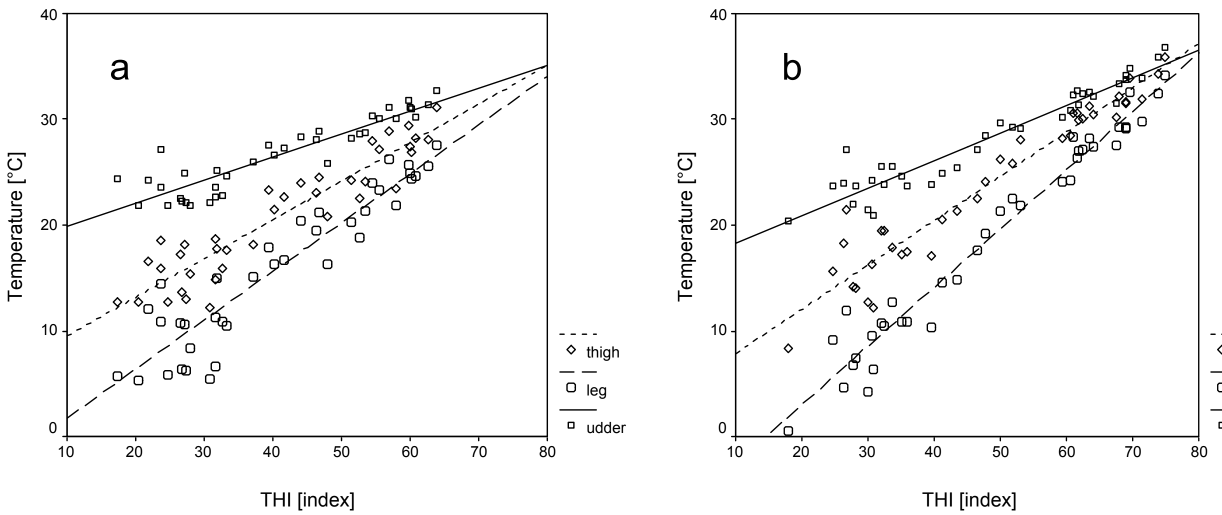

Figure 2: Relationship between the body surface temperature (measured on the tighs, the legs, and the udders), and the temperature humidity index (THI) measured (a) at 8:00 h and (b) at 17:00 h.

Lying behaviour

The duration of lying behaviour was significantly shorter during the day (35·5 ± 7.4 min/h) compared with the night (39·6 ± 5.4 min/h) (P < 0·0001). In addition, the cows laid down significantly less often during the night (0·61 ± 0·16 frequency/h) than during the day (0·73 ± 0·17 frequency/h) (P < 0·0001). The duration of lying behaviour during the day decreased significantly with an increasing THI (P < 0·0001, Figure 3a). The frequency of lying down was not significantly influenced by THI during the day. There were no significant effects of THI on lying behaviour during the night, but significant differences between farms both for the duration of lying behaviour (P < 0·01) and for the frequency of lying down (P < 0·05). There was also a significant interaction between THI and farm for the duration of lying behaviour (P < 0·05) during the night.

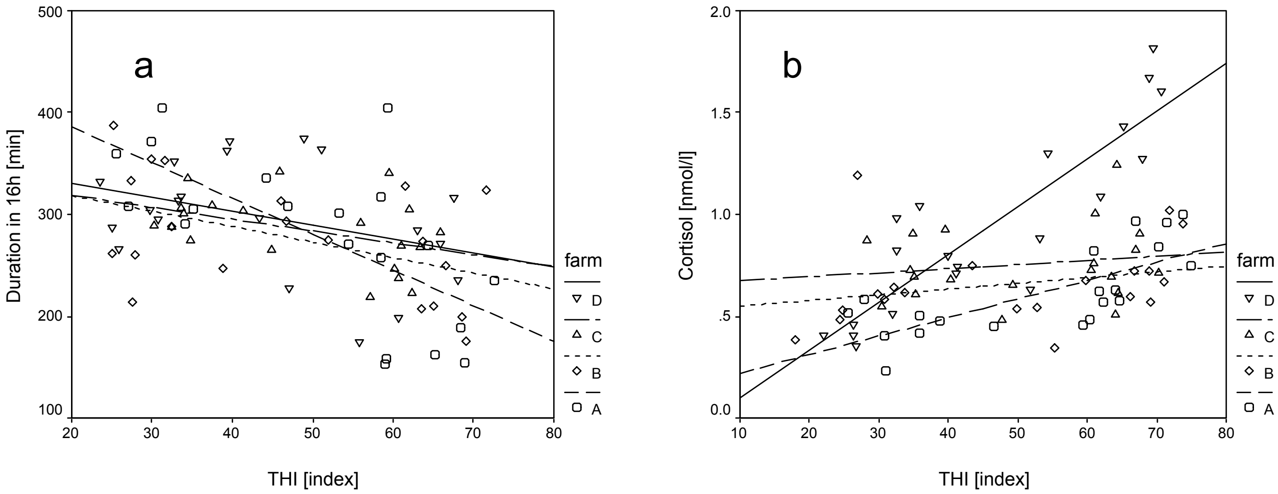

Figure 3: Relationship between (a) the duration of lying and the temperature humidity index (THI) during the day and between (b) the milk concentration of cortisol and the temperature humidity index (THI) measured at 17:00 h.

Heart rate

The cows' heart rate was significantly higher during the day (76·2 ± 4·2 bpm) than during the night (74·5 ± 4·9 bpm) ($P < 0·0001$). Heart rate measured during the night was not affected by THI, but differed significantly between farms ($P < 0·001$). In addition, there was a significant interaction between THI and farm ($P < 0·05$). With regard to the heart rate measurements during the day, we only found a significant interaction between THI and farm ($P < 0·05$) but no significant effects of THI or farm.

Cortisol concentration

The cortisol concentration in the milk samples taken at 08:00 h (1·114 ± 0·299 nmol/l) was significantly higher than in the samples taken at 17:00 h (0·745 ± 0·307 nmol/l) $P < 0·0001$). For the cortisol concentrations at 08:00 h we found no significant effects of THI or farm, but a significant interaction between THI and farm ($P < 0·05$). At 17:00 h the cortisol concentration significantly increased with an increasing THI ($P < 0·0001$, Figure 3b). Moreover, it differed significantly between farms, and there was a significant interaction between THI and farm (both $P < 0·0001$).

Discussion

The THI values in our study ranged from 13 to 75. The maximum THI did thus not reach values encountered in studies carried out on farms in tropical regions. Hahn et al. (1998) classified values up to 74 as "normal", values from 75 to 78 as "alert", values from 79 to 83 as "danger" and a value of 84 as "emergency". To our knowledge, the THI has not yet been used in other studies on cattle kept in (temporarily) cold regions. It is thus not possible to place the minimum value encountered in our study in context.

Our results show a significant positive correlation between THI and body surface temperature during both day and night. Likewise, the rectal temperature and the cortisol concentration in milk obtained at 17:00 h increased with an increase in THI, and the time spent lying at day time decreased. In contrast, the values of these measures were not related to the THI when obtained at 08:00 h or during night. These findings thus indicate that the prevalent climatic conditions induced various thermoregulatory responses especially during the day when the air temperature was always higher compared to the night. This is in accordance with the results of other studies showing that cows have more difficulties to cope with increased air temperatures (Alvarez and Johnson, 1973; Naunheimer-Thoneick et al., 1988; Legates et al., 1991; Lacetera et al., 2002) than with low temperatures (Broucek et al., 1997; Wassmuth et al., 1999). As expected, the body surface temperature measured on peripheral parts of the body such as the thigh and the leg were more affected by the THI than the surface temperature measured on the udder.

Neither the heart rate nor the frequency of lying down was significantly affected by THI during the night or at day time. The activity level of the cows and probably also management routines on a given farm seem to have a greater influence on these two parameters than the climatic conditions. Moreover, Miescke et al. (1978) reported that there is much variation between individual cows in the change of heart rate when experimentally exposed to an increase in air temperature. We can not exclude, however, that more extreme values of THI than those recorded on the experimental farms could result in significant effects on heart rate and lying down frequency.

With most of the physiological and behavioural parameters used in this study we also found significant differences between the farms as well as significant interaction effects between THI and farm. This could indicate that the cows kept on the four farms differed in their physiological and behavioural responses to given climatic conditions. It is more likely, however, that the design of the housing systems included in the study had an influence on the microclimates to which the cows had to adapt. As can be seen from the results presented in Figures 1, 3, 4 and 5, the farm effects can not be attributed to the data of one specific farm. For example, whereas the effect of THI on the rectal temperature measured at 08:00 h was quite different for the data collected on farm C, the relationship between the cortisol concentrations and the THI was rather different for the data of farm D.

Generally, the climatic conditions on the four study farms with temperatures ranging from -13·8°C to 28·7°C can not be considered as extreme. Nevertheless the cows showed both physiological and behavioural responses, and there was even a significant effect of THI on the rectal temperatures measured at 17:00 h. Yet, most measurements of rectal temperatures were within the range from 38·2°C to 38·8°C and the observed increase of cortisol concentrations in milk was relatively modest (less than twice except for farm D). Thus, it can be assumed that the cows were hardly exposed to severe cold or heat stress.

In this study the skin temperature was measured with two different methods. Whereas with the thermography different areas at the skin could be measured very precisely, the sensor fitted into a belt allowed a continuous measurement of skin temperature which was not possible with the thermography. The values obtained by both methods reflected the effect of the THI in a comparable manner. Interestingly, the skin temperatures measured on the anterior part of the rump by means of the sensor were similar both in absolute values and in their reaction to changes in THI to the values recorded on the udder by means of thermography. It is possible that the temperature of the skin under the belt was somewhat increased due to an insulating effect of the belt. However, Spain and Spiers (1998) also reported skin temperatures of 32 to 35°C measured by means of an infrared thermometer in various parts of the rump in dairy cows kept in climatic chambers at a temperature of 18°C.

Our results indicate that the climatic conditions prevalent on the farms during the day induced stronger thermoregulatory responses in the cows than the conditions prevalent during the night, but did not overtax the animals' capacity to adapt. Consequently, the housing of dairy cows in open farm buildings should not result in animal welfare problems under the climatic conditions measured on the study farms. However, it should be considered that the focal animals of our study were lactating. The effect of climatic conditions on thermoregulatory responses may be different for dry cows and also for individuals in specific situations, for example for sick animals and for newly introduced animals that have not yet adapted to the climatic conditions. To prevent thermoregulatory problems in such animals the housing system should preferably provide areas differing in microclimate.

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