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Original Paper

Modelling of the efficient system of the daylighting in a stable for dairy cows

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ABSTRACT

In the article, we focused on the modelling of the uniformity of daylighting in a stable for dairy cows, depending on the opening structures in the roof of the building. We verified size effect of lighting openings on the daylighting in the stable. To the assessment of daylight was designed stable in which we have changed the size of the openings in the ceiling - roof construction. Ground plan dimensions and the size of the side openings remained the same. By using the program WDLS 5.0 we calculated values of daylight factor in the five possible solutions. In the first solution daylight was coming only from the sides. In the second to fifth solutions were also the upper lighting, which was ensured through the upper windows and skylight. In these solutions were changing the sizes of the upper openings. Researched points were evenly distributed over the entire stable area. From the results, we have found that for large widths are not only the side opening constructions but also the upper opening constructions. The best lighting conditions are achieved at an equally spaced upper windows and skylights.

KEYWORDS: daylight, daylight factor in stable, opening structures, WDLS program

JEL CLASSIFICATION: C 63

INTRODUCTION

The quality environment in the stables is important for health as well as the usefulness of dairy cows. The buildings for livestock breeding therefore must be made so, as to ensure a healthy indoor environment and do not jeopardize the stabling and breeding [6]. It is therefore necessary to monitor in the stable microclimatic characteristics of the environment as well as air-containing gases, dust and microorganisms, which are by-product of the decomposition animal excrements often due to imperfect metabolism of nutrients [4]. One

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important factor of the quality of the environment is also daylighting. In the building is lighting beside the heating and ventilation third component of technical security of internal microclimate. It creates not only favourable conditions for working people but also suitable photobiological conditions for the animals [2]. According to Chastain [3], proper lighting is an environmental factor that is often overlooked or given little attention during the planning, construction and maintenance of livestock facilities. However, it is just as important to the efficient operation of a livestock operation as ventilation, heating, or cooling. Daylighting can be obtained from the side openings and the roof structure by means of roof windows and skylights. The disadvantage is that, ridge skylights lighting improved, but in the summer poses a risk of increased thermal load of animals [5].

MATERIAL AND METHODS

To assessing of daylighting in the stable for different types of upper lighting we simulated a stable. Interior dimensions of the stable were 66.16 m x 28.05 m. Dimensions of gates and side openings were in all cases the same. They were changed only openings in the roof ceiling structure. In the front walls of the stable were six gates, on both sides the same. Two sets of gates had dimensions 2.7 x 3.0 m; two sets 3.0 x 3.0 m and two sets 2.7 x 2.9 m. On the one side wall were 11 openings, one of them had dimensions 4,744 x 1,427 mm, nine openings had dimensions 5,828 x 1,427 mm and one opening had dimension 5,244 x 1,727 mm. Lying opposite side wall had 12 openings, where one had dimension 994 x 1,427 mm, eight had dimensions 5,828 x 1,427 mm, other dimensions were 1,264 x 1,427 mm, 1,764 x 1,427 mm 5,244 x 1,427 mm. In the middle of the stables were the columns with circular section, with diameter of 150 mm. In the roof ceiling structure, we considered with five possible solutions.

In the first solution (I) was no opening in the roof ceiling structure.

In the second solution (II) was in the roof placed skylight, which had dimensions 2.4 x 54 m. It was in the middle of the roof located.

The third solution (III) was a stable with roof windows. In this case had skylight, which was placed in the middle of stable dimensions 65,760 mm x 1,000 mm. In addition, there were 28 equally spaced roof windows with dimensions 1,200 x 1,800 mm.

The fourth solution (IV) – stable with roof windows 1 had the same dimension as the skylight in the third solution 65,760 x 1,000 mm. There were 28 roof windows too, their dimensions were 1,400 x 2,000 mm.

The fifth solution (V) – stable with roof windows 2 had dimensions of skylight as in the second solution 2.4 x 54 m. There were 28 roof windows too and their dimensions were 1,600 x 2,000 mm.

In the Figure 1 we can see an example of spacing of openings in the roof of building. Daylight factor is calculated according to equation (1):

$$D = \frac{\overline{E}}{\overline{E}_h} x100 \ (\%) \qquad (1)$$

where: D – daylight factor (%),
$\bar{E}$ – average illuminance in the point of the given plane of indoor premises (lx),
$\bar{E}_h$ – average value of outside comparative illuminance (lx).

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The assessment points, where values of daylight factor were calculated using software WDLS 5.0 (WDLS 5.0 is software from programmers at ASTRA MS Software, s.r.o. for the calculation of daylighting, daylight factor and a mixed lighting), were equally spaced all over area of stable amounting to 0.5 m above the floor. This height is the height of measurement of physiological and working lighting for object with beef-cattle. Number of rated points was 198. Points were arranged in nine rows and twenty-two profiles (Figure 2).

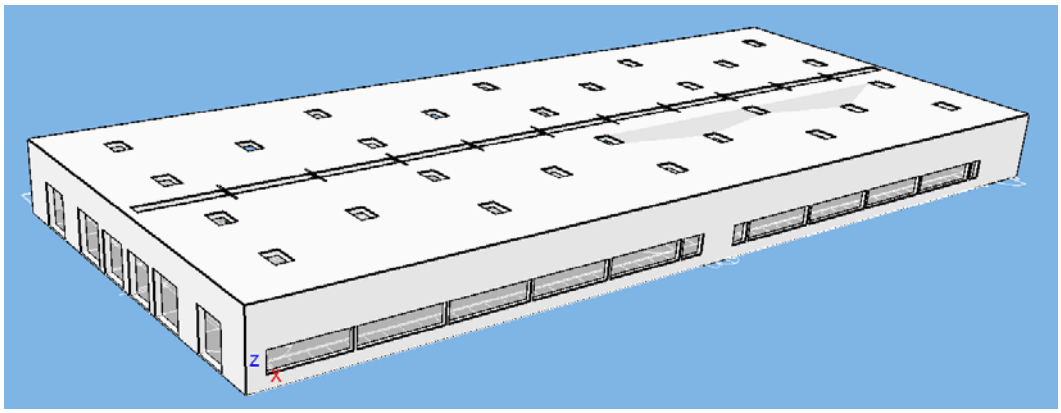
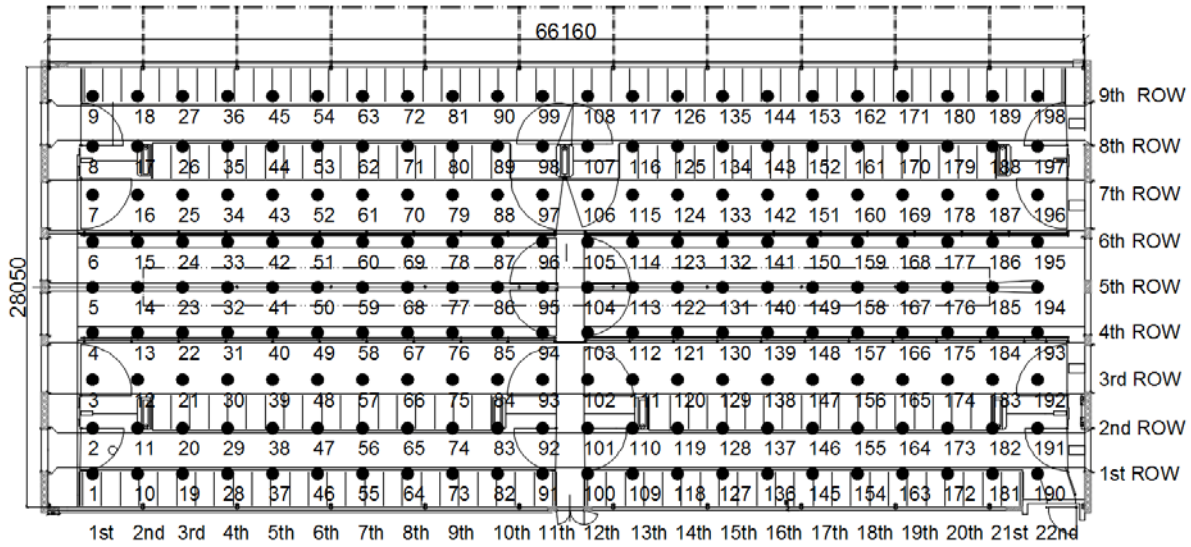


Figure 1 Location of openings in the roof of the building. Source: authors



1st – 22nd: numbers of profile
● 1 – ●198: numbers of measuring points

Figure 2 Plan of the assessed object and measuring points. Source: authors

Uniformity of daylight (U_o) is an important parameter in monitoring the stable building. For indoor premises with upper or combined lighting, the following relationship applies:

$$U_0 = \frac{D_{\min}}{D_m}, (-) \qquad (2)$$

where: D_{min} – lowest value of daylight factor (%),
D_m – average value of daylight factor (%).

According to STN 36 00 88, the minimum value of daylight factor (D) in the stable for free stall for dairy cows should be 1.0 %. The uniformity of technological lighting for animals (U_o) in spaces for dairy cows should be 0.2 [2].

RESULTS AND DISCUSSION

In the Tables 1 and 2 there are the results of the demonstrative examples. The selected assessed points were in first and 10th profiles and in second and 5th row for all solutions of stables. The first profile is close to the open barn-doors (Figure 2), tenth profile is located approximately in the middle of stable. The second row is formed in cubicles, which are in the longitudinal wall of the stable located. The fifth row is routed through the feed passage, which is in the middle of the stable. From these tables, have been created summary graphs (Figures 3 - 6). Table 3 shows the minimum, the maximum and average values of daylight factor and daylight uniformity values for individual solutions. All the values were calculated using the software WDLS 5.0.

Table 1 Values of daylight factor on various types of roof construction in 2nd and 5th row

The serial number of point	Solut. (I) D, % 2nd row	Solut. (I) D, % 5th row	Solut. (II) D, % 2nd row	Solut. (II) D, % 5th row	Solut. (III) D, % 2nd row	Solut. (III) D, % 5th row	Solut. (IV) D, % 2nd row	Solut. (IV) D, % 5th row	Solut. (V) D, % 2nd row	Solut. (V) D, % 5th row
1	3.8	4.9	4	4.6	7.3	12.2	7.7	13.4	7.8	9.8
2	1.7	1.5	2	4	4.6	7.5	5.4	9.6	5.8	7.8
3	1.3	0.8	1.7	7.4	2.9	5.6	3.9	8.1	4.1	11.5
4	1.1	0.6	1.6	9.1	3.2	5.1	3.9	7.3	4.4	13.2
5	1	0.5	1.6	9.4	2.8	5	3.5	7.1	4	13.7
6	1	0.4	1.6	9.4	3.2	5.6	3.9	7.9	4.5	14.6
7	1	0.4	1.6	9.4	3.5	6.1	4.3	7.5	5	15.1
8	0.9	0.4	1.6	8.7	2.6	4.9	3.2	7.5	3.8	12.5
9	0.9	0.3	1.5	9.2	2.9	6.1	3.5	7.1	4.1	13.4
10	0.9	0.3	1.3	8.8	2.5	6.2	3	7.3	3.5	12.9
11	0.8	0.3	1.2	8.9	3	6.5	3.6	8.2	4.2	14.3
12	0.8	0.3	1.2	8.9	2.9	6.6	3.6	8.2	4.3	14.5
13	0.9	0.3	1.3	8.8	2.4	6.2	2.9	7.2	3.5	12.9
14	0.9	0.3	1.4	9.2	2.9	6.1	3.5	7.1	4.1	13.4
15	0.9	0.3	1.5	8.7	2.6	4.9	3.2	7.2	3.8	12.4
16	1	0.4	1.6	9.4	3.5	6.1	4.2	8.1	4.9	14.9
17	1	0.4	1.6	9.4	3.2	5.6	4	8	4.7	14.8
18	1	0.5	1.6	9.4	2.8	4.9	3.4	7.4	3.9	13.7
19	1.1	0.6	1.5	9	3.1	5.1	3.8	7.3	4.3	13.1
20	1.1	0.8	1.5	7.4	2.6	5.5	3.6	8.1	3.8	11.2
21	1.4	1.5	1.7	4	4.2	7.4	4.9	9.6	5.2	7.7
22	3.5	4.9	3.7	5.5	6.6	12.1	7.2	13.5	7.5	9.9

Source: authors

Table 2 Values of daylight factor on various types of roof construction in 1st and 10th profile

The serial number of point	Solut. (I) D, % 1st prof.	Solut. (I) D, % 10th prof.	Solut. (II) D, % 1st prof.	Solut. (II) D, % 10th prof.	Solut. (III) D, % 1st prof.	Solut. (III) D, % 10th prof.	Solut. (IV) D, % 1st prof.	Solut. (IV) D, % 10th prof.	Solut. (V) D, % 1st prof.	Solut. (V) D, % 10th prof.
1	5.2	3.1	5.3	3.4	8.9	5.4	9.1	5.5	9.3	5.8
2	3.8	0.9	4	1.3	7.3	2.5	7.7	3	7.8	3.5
3	4.8	0.5	5.2	1.6	9	2.5	9.5	3	9.3	4.2
4	4.8	0.4	5.9	5.2	10.8	4.1	11.5	5.1	9.9	8.3
5	4.9	0.3	4.6	8.8	12.2	6.2	13.4	7.3	9.8	12.9
6	4.8	0.4	5.2	5.2	10.6	4.1	11.2	4.8	9.8	8.3
7	4.8	0.5	5	1.6	8.9	2.5	9.3	3.1	9.2	4.3
8	3.8	0.9	3.9	1.3	7.1	2.5	7.4	3	7.7	3.6
9	4.8	3.4	4.6	3.1	8.2	4.9	8.4	5.2	8.6	5.5

Source: authors

Table 3 Values D_{min}, D_{max}, D_{av} and U_o for different types of solutions. Source: authors

Solution	D_{min}, %	D_{max}, %	D_{av}, %	U_o, -
(I)	0.3	5.2	1.6	0.06
(II)	1.2	9.4	3.6	0.13
(III)	2.4	12.2	4.8	0.20
(IV)	2.8	13.5	5.5	0.21
(V)	3.5	15.1	6.9	0.23

D_{min} – minimum value of daylight factor
D_{max} – maximum value of daylight factor
D_{av} – average value of daylight factor
U_o – uniformity of daylight
Source: authors

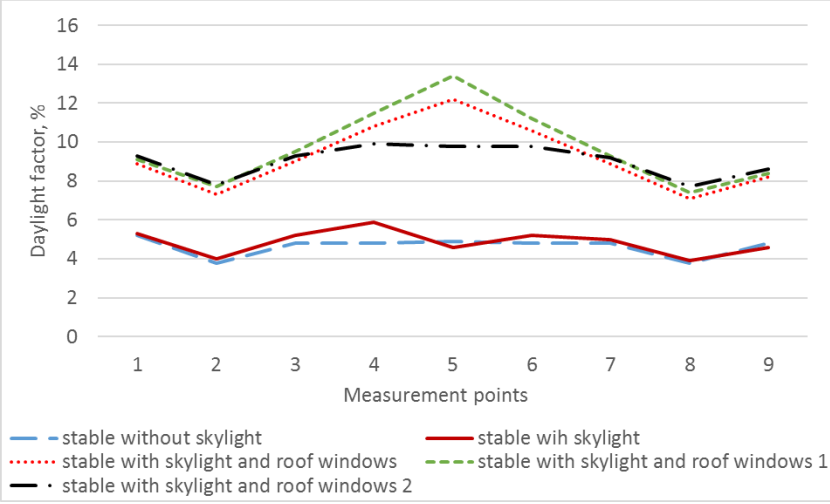


Figure 3 Values of daylight factor in the 1st profile. Source: authors

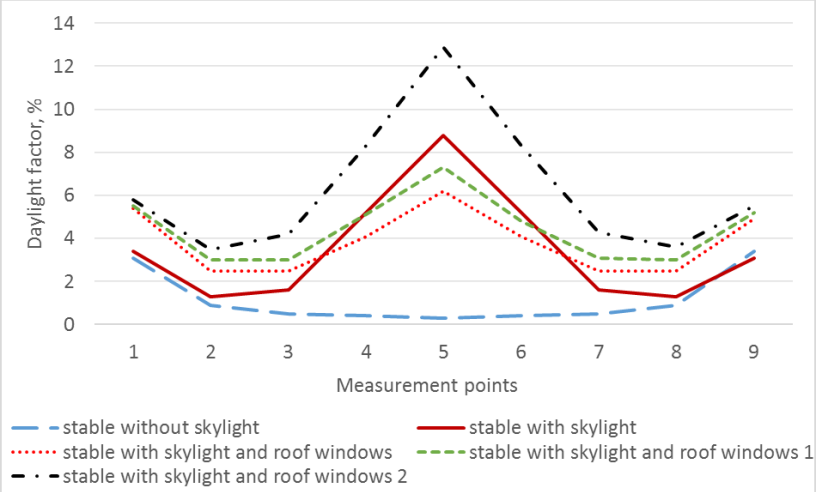


Figure 4 Values of daylight factor in the 10th profile. Source: authors

Figure 3 shows course of lighting in individual solutions in the first profile, which is located near the open barn-doors. In this part impact on except for side and roof windows and skylights also open barn-doors. Here in the first and second solution are values approximately the same, because this part does not affect skylight. In this section are the best values obtained in the fourth solution, which are large enough roof windows and skylight is also over this part of stables. In the tenth profile (Figure 4) did not affect already opened barn-doors on the lighting. Here is clearly see the difference in the values of daylight factor for individual solutions. While in the first solution calculated values did not reach desired values, in the fifth solution these values were exceeded many times over.

Figure 5 shows course of daylight factor values in the second row, which was in the cubicles by the longitudinal wall of stable. In this solution, the best lighting in all cases was near open barn-doors. Other assessed points were near the open side walls. In this section was the effect of skylight minimal. Here the lighting has been affected by skylights. Here we can see, that the best results were in the fifth solution, where were sufficiently large skylight and at the same time sufficiently large roof windows. In the Figure 6 is shown course of the lighting in the fifth row, which is in the part, where is the feed passage. Due to the fact, that above this part is skylight (except solution I) here is the best to see difference in daylighting in the individual solutions. In the solution without skylight here resulting values did not meet standard conditions [8]. In the other cases, this condition significantly exceeded.

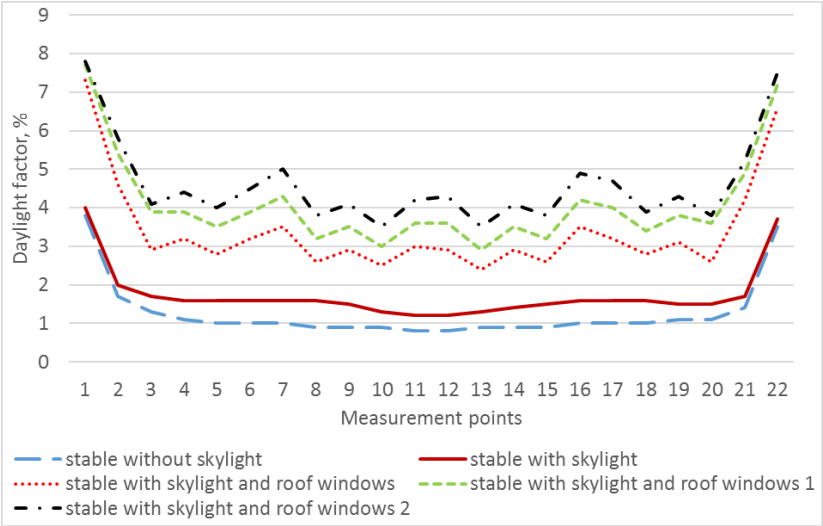


Figure 5 Values of daylight factor in the second row. Source: authors

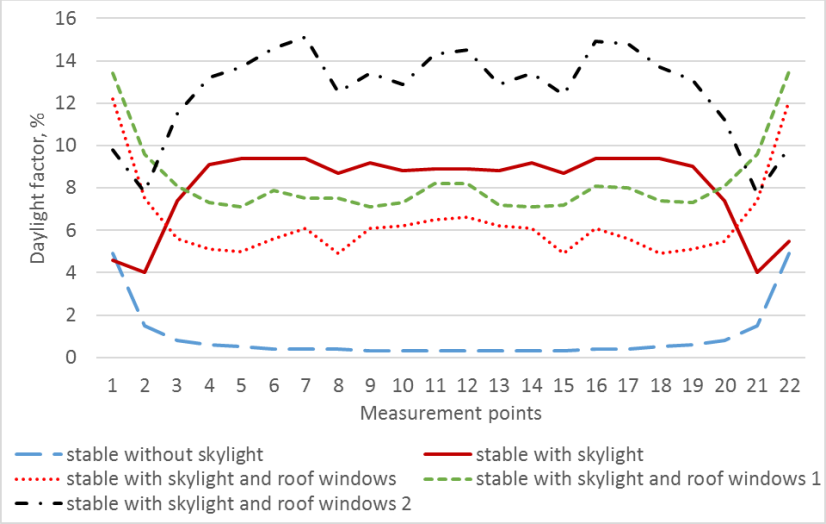


Figure 6 Values of daylight factor in the 5th row. Source: authors

From the above results, we found that the worst daylighting is in the stable, where opening constructions only in the side walls of stable are. In the cubicles located in the side walls of the stables it is sufficient lighting. Towards the middle part the lighting conditions worsen and fall short of the desired values already. It is equally low value of uniformity of daylighting. In the second solution, where was in the middle part of the stable skylight, lighting conditions significantly improved. They satisfy the conditions for housing animals. However, the light in the stable was unevenly distributed. Under the skylight were significantly higher values. In the following three solutions, we have tried to improve the uniformity of daylighting by evenly spaced roof windows. The best results were at the fifth solution. Influence of skylights on a daylighting in the stable we can see in the specific example where we measured values of illuminance [1]. By the longitudinal walls and under the skylight there were high values of daylight factor, however inside the stable they did not fulfil the conditions for housing animals.

In the Figure 7 is the stable with the worst daylighting (solution I) and in the Figure 8 is a view into this stable. In the Figure 9 is the stable with the best daylighting (solution V) and in the Figure 10 is a view into this stable.

Improvement of lighting conditions can worsen thermal conditions in the stable. The problem occurs mainly during the summer period. In this case, it would be necessary to address, what material is the best used for glazing. Temperature increase in the interior due to the opening constructions is affected by many factors. It is kind of glazing, glass thickness, the location of the openings with respect to the points of the compass, the size of the openings and so the like. Vanhoutteghem at al. [9] dealt with the effect of windows for daylighting and thermal comfort in buildings. He focused on the relationship between the size, orientation and characteristics of glazing. For glazing opening structures is appropriate to use materials, that transmits light but reflect sunlight. Samant and Sharples [7] investigated the effect of surface reflectivity to average daylight factor in the atrium of the building, in which they discovered the importance of reflective properties of surfaces atrium and changes in the distribution of the reflectivity of the daylight in the atrium of the building.

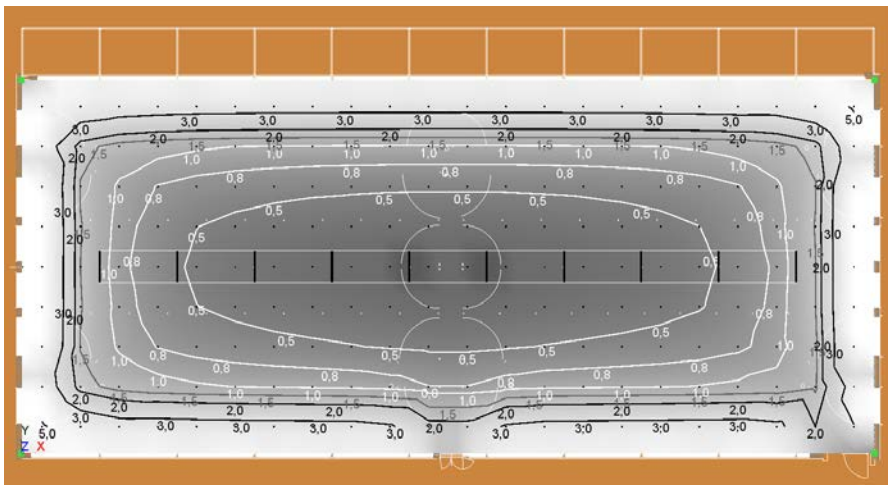


Figure 7 Stable without skylight – solution I. Source: authors

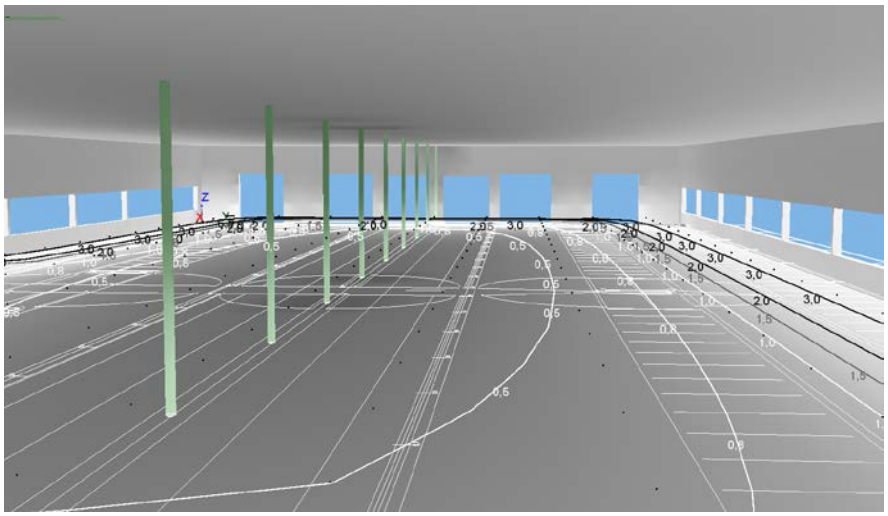


Figure 8 View into the stable with the worst daylighting - solution I. Source: authors

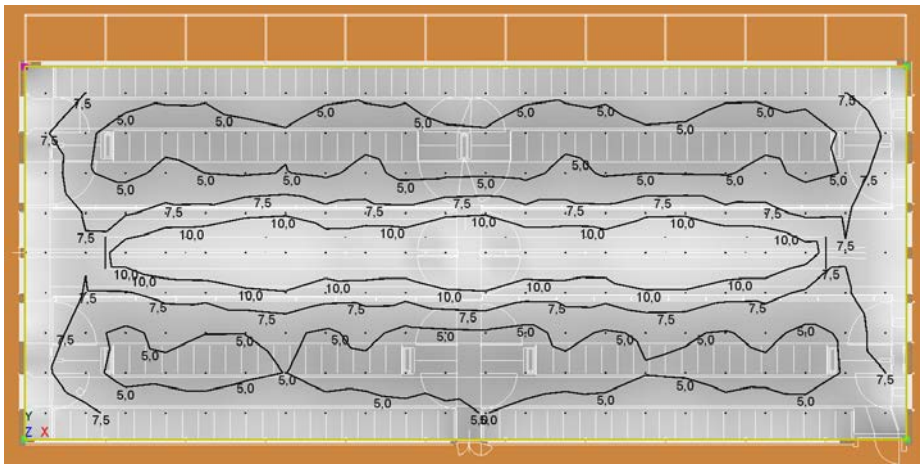


Figure 9 Stable with roof windows 2 – solution V. Source: authors

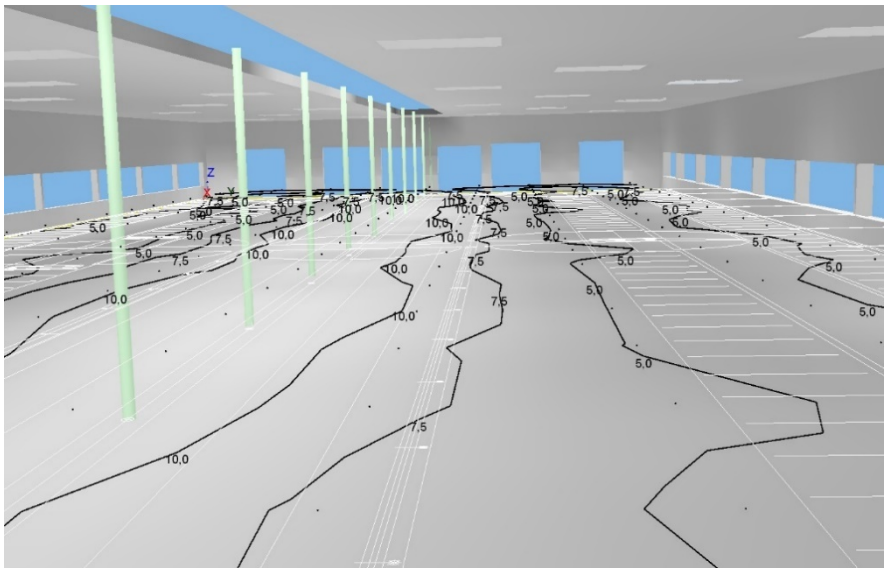


Figure 10 View into the stable with the best daylighting - solution V. Source: authors

CONCLUSIONS

The lighting in the stables for dairy cows is one of the basic parameters of environmental engineering. Many authors have focused on the influence of lighting on the health and cow production efficiency. It has been shown that well-designed lighting has a positive effect on dairy cows. The best lighting is from a health and economic aspect just natural lighting. That is just it important already during the drafting of the new respectively reconstruction of the original stables also focus on the fact make them well designed light openings.

In the article it was proposed five possible options of daylighting. Ground plan dimensions of stable as well as side openings and barn-doors were identical in all cases. It has been changed only roof ceiling structure. From the results, we can see that right plan lighting elements in the ceiling structure are the best solution. In proposals of daylighting it is also important that there was light in the building evenly distributed. That some parts were not too light-filled and on

the other hand, some parts dark. It is best to see the differences in the proposals I and V. In the first solution, we have in the roof structure no opening and part of the stable is, despite the large openings dark. In the fifth solution the light is most evenly deployed. For the draft of roof windows and skylights we must bear in mind what material suggest glazing openings. Here we must see to it that the stable especially in the summer does not overheat.

ACKNOWLEDGEMENTS
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