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RECOMMENDED PROCEDURE FOR HEADROOM DESIGN ACCORDING TO GEOMETRIC PARAMETERS OF BUILDING STRUCTURES

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Abstract.

The system of Czech technical standards for geometric accuracy assumes that the designer determines the functional geometric parameters for a specific building. By calculation, he verifies them in the so-called "geometric plan" in the project documentation. The functional geometric parameters should be determined primarily for critical elements, i.e. for structures whose geometric accuracy is important for the execution of subsequent works, such as technologies requiring high precision and specific structures. The assumption is that designers will incorporate variations in geometric accuracy primarily in the development of the spatial parameters of the structures, which should ensure that the dimensional requirements for the completed structures will be met. One of these parameters is headroom. The design of headroom must respect the minimum height requirements prescribed by legislation, and where appropriate, by technical standards. At the same time, the design must respect the technological possibilities of the construction of individual structures – geometric deviations. To comply with the dimensional requirements for the completed structures, the geometric accuracy deviations should be determined in accordance with the requirements of the technical standards for the execution of the individual parts of the building structures and/or for their design. The aim of this article is to establish a calculation procedure for determining the safe design clearance so that the requirements of the legislation are met after implementation. The increase is determined based on a calculation procedure of the limiting geometric deviations that may affect the resulting headroom.

Keywords: Headroom, geometric accuracy, limit deviation, geometric accuracy deviation.

1. Introduction

The headroom is a geometric parameter that is very important for several room types. Particularly in residential, administration or school buildings and their parts (bedrooms, living rooms, classrooms, offices, etc.), the national building regulations usually stipulate a minimum headroom that should be maintained even after the construction is completed [1, 2].

The minimum headroom is usually set to ensure that the quality and required values of the indoor climate parameters (especially maximum CO_2 values, etc.) can be maintained. The values of these parameters are usually dependent on the geometric dimensions of the rooms under consideration, and the value of the headroom can positively or negatively influence the indoor environmental parameters, especially for naturally ventilated rooms [3].

The main goal is to design and implement the dimensions of buildings so that people feel as comfortable as possible in them. Practically, this means that the dimensions must be appropriate, ceilings high enough, doorways and hallways wide enough, and so on.

It is not surprising that investors strive to ensure that the required minimum headroom is always met, therefore, this parameter is often checked after the completion of the building. To comply with the minimum headroom requirement, the projected headroom must be designed with a margin, which, even after allowing for deviations in geometric accuracy for the construction, anticipated deflections of the ceiling slab and surface finishes, will ensure that the required minimum headroom is maintained after completion.

This paper proposes a procedure for calculating the recommended headroom using limit deviations of geometric parameters that can affect the actual headroom. The calculation procedure can be used for the design and control of the proposed clear height of newly designed rooms in civil engineering buildings. The calculation considers variations in geometric precision for the execution of the structures that may affect the resulting clearance value and the results of actual height measurements carried out on construction sites.

The analysis of technical standards shows that the headroom can be influenced by the following geometric parameters, in particular:

- deviation of the construction height,
- deviation of floor thickness,
- deflection of the ceiling slab.

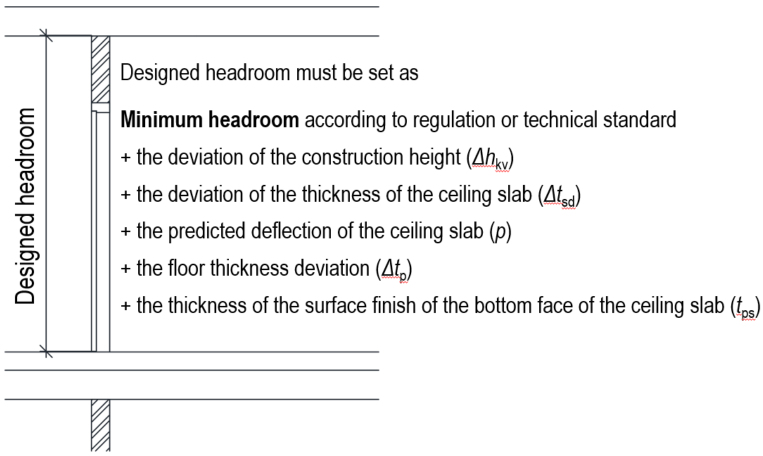

Figure 1. Determination of design headroom.

Therefore, the geometric accuracy of not only the non-finished structure itself, but also the deviations of the floor, the bottom face of the ceiling, and the deflection of the ceiling slab must be considered in the design and implementation of the structure according to Figure 1. The permissible deviations of the load-bearing structures, thickness of the floor, the proposed ceiling slab deflection and the surface finish of the ceiling must, therefore, be added to the minimum headroom [4, 5].

2. Materials and methods

2.1. Calculation of the recommended headroom

Based on the analysis of deviations in geometric accuracy and other parameters of horizontal structures, a procedure for calculating the recommended headroom was proposed, which can be used by the designer in the design documentation phase and by the contractor to check the accuracy of the design documentation. The calculation procedure is described below, including all the variables that should be considered in the calculation.

The recommended headroom ($h_{sv,dop}$) shall be calculated according to the following relation:

$$h_{sv,dop} = h_{norm} + t_{ps} + (\Delta h_{kv} + \Delta t_{sd} + \Delta_t p) \times k_{0.95}, \quad (1)$$

where h_{norm} is the required minimum headroom according to a technical standard or regulation, t_{ps} is the thickness of the surface finish of the bottom face of the ceiling slab, Δh_{kv} is the deviation of the construction height, Δt_{sd} is the deviation of the thickness of the ceiling slab, Δt_p is the floor thickness deviation, p is the predicted deflection of the ceiling slab and $k_{0,95}$ is the probability coefficient of maximum deviations.

In the case of a structure with a false ceiling, it is not necessary to take into account the surface treatment of the ceiling, i.e. $t_{ps} = 0$. If the ceiling finish is a free height false ceiling, i.e. a false ceiling whose minimum height is not related to the type of technology to be installed in the false ceiling and its installation space, the assumed ceiling deflection can be omitted from the above relation, i.e. $p = 0$.

The deviations are considered in positive values. The geometric accuracy deviations are based on the parameters specified in the relevant technical standards for construction.

The applicable limit deviations of headroom should be indicated on the drawings in one of the following ways:

- by setting limit deviations within the quoted dimensions, e.g. 2650 (±35) or 2650 (+20; −50),
- by specifying limit deviations within the drawing legend notes.

A negative limit deviation cannot be applied to the design minimum headroom determined by a calculation [4, 5].

The procedure for calculating the recommended headroom using the geometric limit deviations of the headroom has been developed on the basis of practical experience, where we repeatedly encounter projects, especially apartment buildings, where the headroom is designed at the limit of the minimum technical requirements. After the completion of the construction, in most cases, the investor complains about non-compliance with the basic technical requirements for buildings (non-compliance with the minimum headroom). In many cases, this problem stems from the design documentation, in which the designer, for some reason, did not respect the recommended deviations in geometric accuracy, deflections, etc., and designed the headroom without any margins. The minimum headroom cannot be guaranteed in the implementation of such a project because the building structures cannot be constructed from a technological point of view without certain deviations in geometric accuracy, even if the contractor is aware of this problem and tries to avoid it.

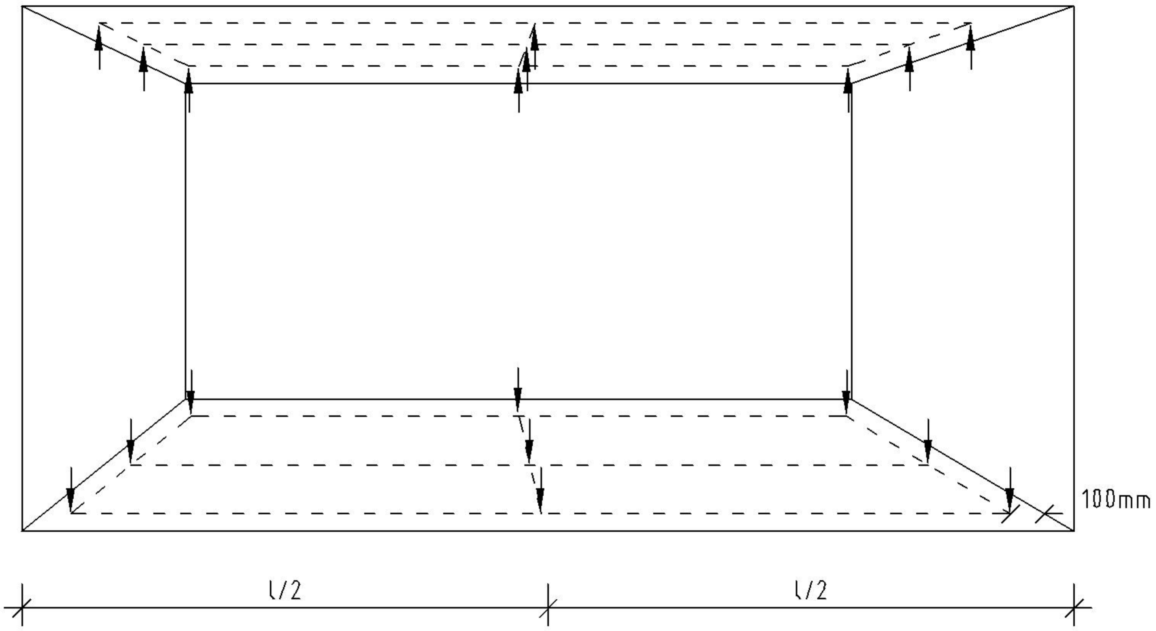

Figure 2. Measurement of headroom [6].

2.2. Measurement of headroom

To be able to assess whether the calculation of the headroom including the deviations of the geometric parameters is justified, experimental verification of the actual headroom on selected projects was carried out. The measurement of the headroom was always carried out in residential rooms that have a minimum headroom prescribed by the regulation, which must be respected [1, 2]

The headroom of the space under consideration (living room, bedroom, etc.) is the distance between the floor surface and the bottom face of the ceiling, or the lowest element of the ceiling (false ceiling, beams, column heads, plaster) because it should delimit a space in which a smooth horizontal and vertical movement is not impeded.

The heights of the rooms were measured at the distance of 100 mm from the walls, columns, and in the middle of the length and width of the room. The heights of openings and similar structures are checked 100 mm from the face of the supporting structure (wall, etc.), or even in the middle of the plan dimension according to Figure 2. In total, at least nine measurements were taken in each room. A measurement offset of approximately 100 mm from the edges of vertical supports (walls, columns) is recommended due to the occurrence of possible bigger surface irregularities on the edges of the structure [6, 7].

The designed headroom was subtracted from the measured value, and the headroom deviation was determined by relation:

$$\Delta_h = h_{sv,skut} - h_{sv,pd}, \tag{2}$$

where Δ_h is the calculated deviation in headroom, $h_{sv,skut}$ is the measured headroom, $h_{sv,pd}$ is the designed headroom.

The minimum Headroom according to technical standard or Regulation	**No**	**Yes**
Frequency of deviation	58	377
Percentage of all measured deviations	13.33 %	86.67 %

Table 1. The frequency and percentage of measured headroom that do not meet the minimum headroom according to technical standards or law regulations.

3. Results

3.1. Measured headroom deviations

Headroom measurements were taken on a few housing projects that showed an increased risk of noncompliance with the minimum headroom because they were designed to the minimum required value or with only a minimum margin of up to 20 mm. Headroom measurements were taken after completion of the whole building and primarily in bedrooms and living rooms according to Figure 3. Figure 4 shows the frequency of deviations of the measured headroom from the designed headroom.

The evaluation shows that the designed headroom was not respected in most cases, while in about 95 % of the measurements, the actual clear headroom is lower than the designed headroom. In about 13 % of the measurements, the minimum clear headroom requirement for bedrooms and living rooms is not met according to Table 1, even if the minimum clear headroom was designed with a margin of about 20 mm.

Therefore, it cannot be assumed that if the headroom is designed with a minimum or very small margin (up to 20 mm) for geometric inaccuracy of the building

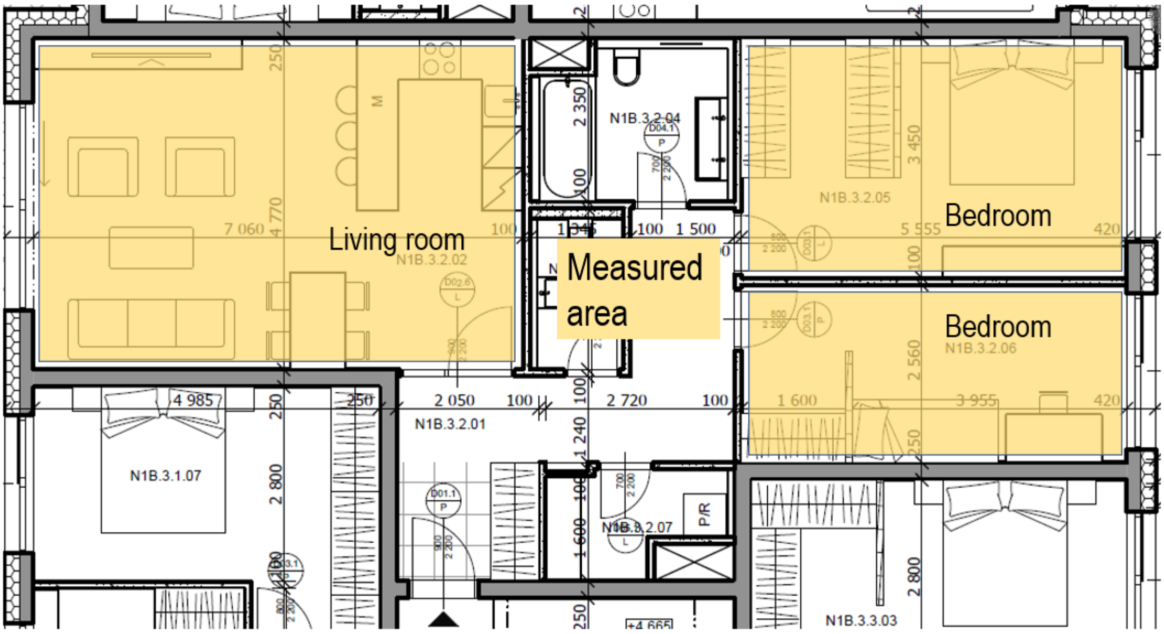

Figure 3. Example of measured area (bedroom, living room).

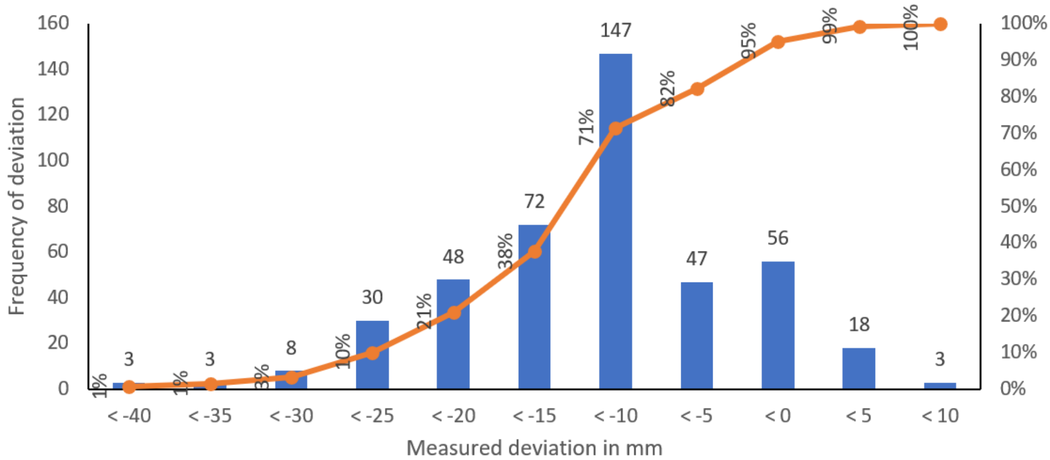

Figure 4. The distribution of measured deviations of headroom according to their value, frequency, and percentage.

structures, it will meet the legislation requirements. From the measurements taken, it can be concluded that the headroom will in fact be reduced, and in about 75 % of cases, the headroom will already be reduced during the rough construction. The design calculation of the recommended headroom, therefore, correctly assumes a margin for deviations in geometric accuracy, ceiling slab deflections and finishes on the underside of the ceiling that are not quoted [8].

3.2. Probability coefficient of maximum deviations ($k_{0.95}$)

Maximum deviations for individual geometric parameters are considered in the calculation of the recommended headroom. In practice, however, it cannot be assumed that all these maximum deviations occur simultaneously. Therefore, a coefficient of probability of occurrence of maximum deviations is implemented in the calculation. The coefficient was calculated for the worst measured clearance deviation, called k_1, and for the deviation that represents 95 % of all measured deviations, but the coefficient $k_{0.95}$ is used in the calculation of the recommended headroom.

The coefficient represents the probability of occurrence of 95 % of all headroom deviations and is determined on the basis of measurements made on site.

For each measured building, the negative clearance deviation representing the 95 % limit of all measured deviations was determined and compared with the maximum possible calculated deviation according to the relation (1) without adjustment by the coefficient $k_{0.95}$ and without deflection according to the following relation:

$$k_i = \frac{\Delta h_{0.95}}{\Delta h_{kv} + \Delta t_{sd} + \Delta t_p}, \quad (3)$$

where $\Delta h_{0.95}$ is the deviation representing 95 % of all measured deviations, Δh_{kv} is the deviation of the construction height, Δt_{sd} is the deviation of the thickness of the ceiling slab and Δt_p is the floor thickness deviation.

The value of the coefficient $k_{0.95}$ is further determined by averaging over all projects by relation:

$$k_{0.95} = \frac{\sum_{i=1}^{n} k_i}{i}. \qquad (4)$$

The current value of the coefficient $k_{0.95}$ was experimentally set to 0.71 [5]. Based on a more accurate analysis of the measured headroom deviations, the coefficient value can now be updated. The resulting value of $k_{0.95}$ is 0.32 according to Table 2.

Probability coefficient of maximum deviations	$k_{0.95}$	k_1
Average of all measured projects	0.32	0.44

Table 2. The value of the probability coefficient of maximum deviations relative to 95 % ($k_{0.95}$) and 100 % (k_1) of all measured deviations.

4. Discussion

From the measured data, it can be expected that the constructed headroom is likely to be lower than the designed headroom in 95 % of cases. This fact is mainly influenced by geometric accuracy deviations brought into the structure during the construction process, which cannot be easily influenced because it is technologically impossible to construct structures without geometric accuracy deviations.

Therefore, when checking the headroom of rooms, two essential factors must always be considered. The first factor is the headroom design factor, i.e. whether the headroom has been designed with the sufficient allowance for variations in geometric accuracy, ceiling slab deflections, ceiling face finishes, etc.

If the project documentation proposes headroom that is in line with the minimum requirements of the technical standards or legislation, it is very likely that the construction headroom will be reduced during the construction process due to the tolerances allowed, and thus not comply with the minimum requirements.

The second factor is deviations in geometric parameters which may affect the constructed headroom. When checking the finished headroom, it is always necessary to check that the structures have been constructed within the recommended tolerances or deviations of geometric accuracy.

Both factors must be considered if there is any doubt whether the resulting headroom complies with legislative requirements.

5. Conclusion

One of the important and characteristic features of quality are the geometric parameters (ground and height dimensions of the designed space) of the element and the structure for which boundary conditions should be set. The room dimension tolerances and measured deviations are the basic parameters that need to be established to achieve the desired result, the headroom of the space. Geometric accuracy and its deviations are often underestimated in the preparation of project documentation, even though the minimum required dimensions are one of the basic contractual and technical parameters of the building as defined in national regulations and contract documents. The failure to comply with them is often severely penalized.

To comply with standard or legal requirements for minimum headroom, the design headroom shall be determined as follows:

$$h_{sv,pd} \geq h_{sv,dop} > h_{sv,norm}, \qquad (5)$$

where $h_{sv,pd}$ is the design headroom, $h_{sv,dop}$ is the calculated recommended minimum headroom, $h_{sv,norm}$ is the minimum headroom according to a technical standard or regulation.

Deviations of a finished headroom shall comply with the geometric accuracy limits specified in the technical standards.

Acknowledgements

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