CONTEMPORARY RESIDENTIAL ARCHITECTURAL DESIGN IN TERMS OF INDOOR ENVIRONMENTAL QUALITY

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ABSTRACT

The quality of indoor environment in buildings is one of the key factors of user satisfaction, as it affects their health and well-being. The indoor environment comprises of several components; the chief among them being the thermal and humidity microclimate, lighting, acoustics and indoor air quality. These can also be summed up by the term “building physics”.

The quality of the final indoor environment is largely decided in the initial phases of the building design. The spatial and material configuration of the house determines most of the daylight, acoustics and thermal qualities of the designed spaces. While, to some extent, it is possible to fix the indoor environment of a finished building by installing additional technologies, it is of course costly in terms of both money and energy efficiency. It is therefore a crucial skill for architects to be able to foresee the impact of their decisions in the early design stages on the indoor environmental quality in the finished building.

Finding a compromise between the often contradictory demands on the individual qualities (for example daylight versus heating) and optimizing the building design in a holistic manner is the other expertise necessary for ensuring a quality indoor environment.

This article illustrates the architectural design process and its connection to the building physics on three examples/case studies of contemporary residential buildings. The individual factors (particularly daylight, thermal qualities and acoustics) are analyzed mostly using software simulation methods. Afterward, the factors and their significance for the building design are synthesized, taking into account also the legislative requirements for residential buildings.

The article is a part of a larger research project which tries to answer the following set of questions: “Which architectural features influence the individual factors of the indoor environment and how?” and “How do the individual factors of the indoor environment interact and influence each other?”

Keywords: Architecture, Indoor environment, Building physics, Design process

INTRODUCTION

In the developed countries, the population spends more than 90% of their time indoors. The majority of that time is spent at home. Since the 1990s, there have been numerous studies proving the link between the quality of indoor environment and the health and well-being of its inhabitants [1]. The indoor environment in buildings can be defined as a *set of physical conditions that surround a person and affect their senses* [2]. These conditions can be grouped into the following categories:

- Thermal and humidity microclimate
- Lighting
- Acoustics
- Indoor air quality
- Electromagnetic, electroionic, electrostatic and ionization microclimate
- Psychological well-being of the user

Although all of these are affected by the architectural design, the first three components (thermal, lighting and acoustics) are the most prominent, at the same time belonging to the scope of building physics.

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The indoor environmental quality is still regarded as somewhat inferior to the environmental performance of the building. However, in the recent years, the indoor environment is starting to gain importance in the professional discourse and its assessment is becoming a part of evaluation tools for the building sustainability [4]. There is a shift from separate components towards a holistic approach that, besides the quantifiable parameters, also takes into account the “soft” parameters, mostly linked to the psychology of users and their behavior[5].

The demands on the indoor environment have undergone a huge transformation, especially in the second half of the 20th century and in the beginning of the 21st century. Until the first half of the 20th century, there were almost no explicitly defined requirements in the quality of the indoor environment. The limiting factor for residential development in terms of street profiles (height and distance between buildings) as well as the building structures was fire safety.

The criteria for the individual aspects of the indoor environment (thermal technology, indoor air quality, luminous and acoustic properties of buildings) were specified in the first half of the 20th century. Besides scientific research, a major starting point for formulating the requirements were the principles of the Athens charter, reacting to the unsatisfactory conditions in dwellings of the 19th and early 20th century. After WW2, legislative documents were drawn. These standards set specific, quantifiable parameters of the individual aspects of the indoor environment. There were also architectural design principles concerning not only the building structures, but also the apartment layouts and even the urban design of the cities. The form of housing neighbourhood in the second half of the twentieth century was largely determined by the daylight requirements. During the second half of the twentieth century, the principles concerning the architectural design principles have changed only marginally, having been transferred into subsequent standards. Some of the quantifiable requirements, mostly on building structures, have undergone quite a steep development. This concerns especially the demands on thermal qualities of the building envelope structures and to some extend the acoustic qualities. The requirements on daylight have changed the least since they were first set (in fact, the contemporary requirements on the daylight factor in the Czech

Republic roughly correspond to the idea formulated by Vitruvius in the first century BC [6]).

Nowadays, there is a lot of requirements placed on the residential development. The dominant factor influencing the form of the dwellings is often the economic aspect, which determines the apartment layout. In the second half of 20th century, during the mass construction of precast panel houses, the majority of apartments were intended for families with children, so there were mostly two bedroom apartments and the smaller, one-bedroom apartments of studios were mostly a supplemental part of the typologies mix. This changes with the demands of the free housing market in the early 21st century, as the lifestyle of the entire society transformed. Nowadays in the cities, the majority of the newly built apartments are one-bedroom.

New dwellings must meet the requirements for building structures, which can be explicitly determined by numerical values and are therefore easier to verify. It is no longer possible for the architect to assess all those requirements and therefore a number of specialized professionals come into play.

METHODS

The connection between architectural features of the building and the physical qualities of the indoor environment is illustrated on example of real residential buildings.

The individual factors (particularly daylight, thermal qualities and acoustics) are analyzed mostly using software simulation methods. Afterward, the factors and their significance for the building design are synthesized, taking into account also the legislative requirements for residential buildings.

The lighting conditions were calculated for the apartments on the ground floor or, in case of Ostravska Brána, on the first floor including apartments, as the shading conditions are the least favourable there. The daylight factor was assessed with total daylight factor on a comparative plane, at a height of 850 mm above the floor under the assumption of the CIE winter sky overcast with a continuous layer of clouds and dark terrain, evaluated in compliance with the legislation valid at time of construction as well as now at two pints in the middle of the room, 1 metre from the side walls. The daylight calculations were performed in the software Building Design by Astra Software, using the computing module Wdls 5.0 – Daylight calculation and ČSN EN 17037 – Daylight of Buildings [7]. The sunlight duration in the rooms requirements are set for March 1st for 90 minutes. The sunlight duration was calculated using the Světlo+ software by JpSoft [8].

For the thermal assessment, we evaluated the insulating properties of building structures, the thermal stability in summer and the possibility of cross-ventilation of the apartments. The evaluated factors for the insulation were the average heat transfer coefficient U_{em} of the building envelope and the heat transfer coefficients of individual envelope structures (or structures at the system boundary of the residential zone of the building), calculated using the software ENERGIE 2019 by Svoboda software [9]. For the summer thermal stability, a critical room was selected in each of the buildings. This means a room that is most likely to overheat, due to its location on the top floor, large glazing area and orientation towards south or west. The criterion is maximum indoor air temperature in the room during the summer $\theta_{ai,max}$, calculated using the software SIMULACE 2018 by Svoboda software [10].

The acoustic assessment consists of two parts: evaluating the soundproofing qualities of the building structures and analysing the noise sources within the buildings layout and their relation to the protected rooms (namely bedrooms).

The airborne soundproofing of building envelope structures, including window fillings, was calculated, as well as the airborne soundproofing of dividing structures between apartments and partitions separating living rooms and the airborne and impact soundproofing of ceilings between residential floors. For this, the software Neprůzvučnost 2010 by Svoboda software [11] was used.

Three multi-family dwellings were selected for the analysis. All of them were built in the Czech Republic in the 21st century. The aim was to cover the specter of typologies used for contemporary residential development in cities.

The first is a residential complex **4Blok** in the wider city center of Prague. It was built in 2015, designed by Chmelař architekti. The building fills an entire urban block and creates a self-contained unit. Out of the 210 apartments, the majority are one-bedroom or studios, although there are also some larger family apartments, complying with the demands of today’s housing market. The 4Blok has two floors of underground parking. Although there are some shops on the ground floor, the building is dedicated almost exclusively to the housing function.

Figure 1 – Housing complex 4Blok (source: archiweb.cz)

Figure 2 – Housing complex 4Blok – floorplan and urban situation

The next building selected for analysis is the apartment house **Ostravská Brána** (Ostravian Gate), built in 2010 in the historical center of Ostrava and designed by KUBA&PILAŘ architekti. This building was selected because it illustrates the necessity of dealing with the urban context of the building, which the architect may often consider more important than the quality of the actual apartments. This building combines the housing function with some more commercial functions: the entire ground floor is used for a café and shops, with some of them extending to the mezzanine as well. The prevailing typology is a two-bedroom apartment.

Figure 3 – Apartment house Ostravska brana (source: archiweb.cz)

Figure 4 – Apartment house Ostravska brana – floorplan and urban situation

The third dwelling, a complex of three villa-houses in **Krásnopolská**, Ostrava, built in 2018 and designed b ATELIER 38 s.r.o., was included as a representation of a transition typology between single and multi-family dwelling. There are seven apartments in each house: 2 one-bedroom apartments, 1 two-bedroom apartment and 4 three-bedroom apartments. The complex is dedicated solely to housing, with no commercial function.

Figure 5 – Villa houses Krásnopolská (source: archiweb.cz)

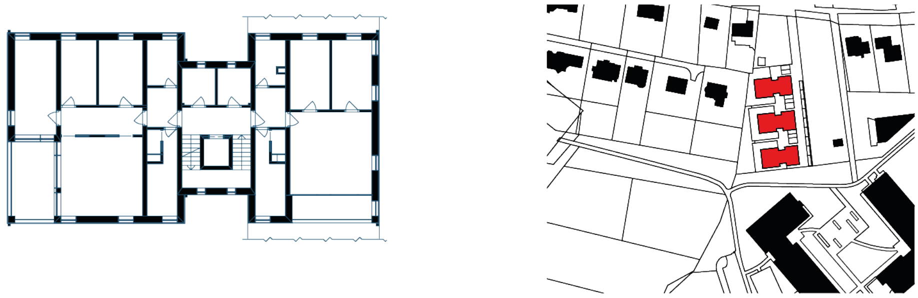

Figure 6 – Villa houses Krásnopolská – floorplan and urban situation

RESULTS

Daylight and sunlight duration

For the 4Blok housing complex, the daylight values in certain apartments on the first floor did not comply with the requirements. This is mainly due to the shading by the balconies of the apartments above. The minimum sunlight duration is met in at least one of the rooms in the apartments. Also in certain apartments in Ostravska Brana, the daylighting requirements were not met due to the shading from surrounding buildings. Some of the apartments also do not have any room that receives the minimum required amount of sunlight. The Czech legislation does however allow exceptions for the building plots in urban environment, so that the vacant lots can be built on. In the villa-houses Krásnopolská, all the rooms meet the requirements on daylight provision and all the apartments receive the sufficient amount of sunlight.

Thermal technology

All the evaluated buildings do meet the requirements on thermal qualities of building envelope structures, as it is in fact not possible to receive a building permit for a new building otherwise.

The requirement on maximum indoor temperature in summer is met only in Ostravská Brána, which has relatively small window openings. The critical rooms in both 4Blok and Krásnopolská exceed the required limit, mainly due to large glazing area in the critical rooms. The problem is solved by installing air conditioning.

Cross ventilation was examined in a typical floor. Out of the 35 apartments on a typical floor of 4Blok, only 5 have windows facing the opposite facades and 6 more face perpendicular facades. The rest of the apartments face only one façade, not allowing for cross ventilation. In Ostravská Brána, 3 out of the 8 apartments on a typical floor are facing opposite facades and allow for cross ventilation, while the remaining 5 are only facing one facade. In the villa-houses Krásnopolská, all of the apartments allow for cross ventilation. 5 of the 7 apartments in each building face opposite facades and the remaining 2 have windows facing perpendicular facades in each room.

Acoustics

All the evaluated building structures comply with the requirements on protection against airborne noise and the floors (and ceilings) meet the limits on impact noise.

Inside the apartments, the most prominent noise source are the sanitary installations and kitchen extractor hoods. The vertical pipes are placed in installation shafts, which are separated in the layouts from the protected rooms. The horizontal pipes are placed in installation prewalls of plasterboard and in the layout, they are kept from the walls adjacent to noise protected rooms, especially bedrooms. These principles were already stated in the early standards from the middle of 20^{th} century and are still relevant nowadays.

On the scale of the house, the largest noise source are the vertical communications – staircases and elevators. In 4Blok apartment complex, the elevator shafts have double walls, with a self-bearing inner shaft and flexible installation of the elevator motor. In Ostravská Brána, the self-bearing elevator shafts are separated from the apartment walls by open vertical apertures. In both aforementioned dwellings, the staircases (made of concrete prefabricates) are adjacent to the apartment walls and it is therefore crucial that they are flexibly attached to the load bearing structure, to protect the rooms against impact noise. In the villa-house Krásnopolská, the vertical communication is located in a distinct building mass and the elevator is placed between the staircase wings, which minimizes potential for impact noise. The staircase itself is adjacent to the apartments walls facing bathrooms and corridors, therefore further protecting the rooms against impact noise.

CONCLUSION

The aim of this article was to compare the indoor environmental qualities of three contemporary residential buildings of slightly different typologies. The calculated parameters were evaluated according to the valid legislation and linked to the architectural features of the buildings.

The smallest differences were found in the thermal and acoustic qualities of the building structures. The demands on those parameters are explicitly stated (usually by a single number) and therefore easily verifiable and compliance with them is necessary to receive the building permit for a new building.

The daylight conditions varied quite significantly. The daylight and direct sunlight provision is determined mostly by the urban situation and external shading, which are prerequisites of the building site. Next determining factor is the apartment layout, along with the size and placements of the windows. The size and composition of the apartments is normally assigned by the developer according to the market demand. It is typically easier to achieve the required sunlight duration in larger apartments which have rooms facing multiple facades.

The apartment sizes and layout also apply to the possibility of cross ventilation. In larger dwellings comprised of smaller apartments, it is often necessary to orient most of the apartments to only one façade to archive an effective layout and minimize vertical communications.

The layout principles related to protection against noise were observed in all the analyzed buildings. However, in the larger apartment houses, the separation of staircases from noise protected rooms was often not possible.

To conclude, the "soft" demands on indoor environmental quality were best met in the villa-houses Krásnopolská, which have the advantage of large apartment layouts and relatively low-density urban context. In the apartment house Ostravská Brána, the most limiting factor was the cramped urban situation of the historical city center, which led to the lowest daylight and direct sunlight provision of all the evaluated buildings. In the housing complex 4Block, the largest limitation to some of the indoor environmental qualities was the large number of small (one-bedroom and studio) apartments, along with the external balconies on the façade.

Although the quality of the indoor environment in dwellings is an important issue, it is far from the only demand placed on the contemporary residential development. The economic factors and the urban context often pose requirements conflicting with those of the indoor environment. The goal of the architect is not to fulfill each of the requirements to the maximum (that would not be possible) but to find optimal balance between all the aspects, playing the difficult role of a mediator.

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REFERENCES

[1] L. Hensen Centnerová, "On the history of indoor environment and it's relation to health and wellbeing", REHVA Journal, vol. 55, no. 2, pp. 14-20, 2018.

[2] Z. Veverková, K. Kabele and P. Dvořáková, "Vnitřní prostředí budov", TZB Haustechnik, vol. 2015, no. 12015, pp. 14-18, 2015.

[3] N. Lechner, Heating, cooling, lighting: sustainable design methods for architects, Fourth edition. Hoboken, New Jersey: John Wiley & Sons, Inc., 2015.

[4] T. Larsen, L. Rohde, K. Jønsson, B. Rasmussen, R. Jensen, H. Knudsen, T. Witterseh and G. Bekö, "IEQ-Compass – A tool for holistic evaluation of potential indoor environmental quality", Building and Environment, vol. 172, 2020.

[5] P. Bluyssen, The indoor environment handbook: how to make buildings healthy and comfortable. Sterling, VA: Earthscan, 2009.

[6] J. Kaňka, "Vitruvius o denním osvětlení a dnešní stavební předpisy = Vitruvius about daylight illumination and recent building regulations", Tepelná ochrana budov, vol. 17, pp. 14-17, 2014.

[7] Autodesk and Astra MS software, "Building design: module Wdls 5.0 (daylighting) and ČSN EN 17037 (Daylight of Buildings)".

[8] JPSoft s.r.o., "Světlo+ version 2_5".

[9] SVOBODA SOFTWARE, "Energie 2019".

[10] SVOBODA SOFTWARE, "Simulace 2018".

[11] SVOBODA SOFTWARE, "Neprůzvučnost 2010".