THE DEVELOPMENT OF INDOOR ENVIRONMENTAL QUALITY DEFINITION FROM VITRUVIUS TO THE PRESENT

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ABSTRACT: This article follows the development of the views and requirements for the indoor environmental quality in buildings throughout the course of the history of architecture. How is the quality of the indoor environment in architecture as a whole perceived by contemporary architects and experts?
One of the primary reasons for building was to create a space “inside”, protected from the surrounding world. The importance of the indoor environmental quality in buildings has already been recognized and described by Vitruvius in the first century BC. Yet only in the first half of the twentieth century, the requirements for the individual aspects of the indoor environment (thermal technology, indoor air quality, lighting and acoustics) were established accurately. These indoor environmental quality requirements are currently ingrained in standards and legislation, and for most of them compliance with the set values is required by law.
The quality of indoor environment in buildings gained importance especially at the end of the twentieth and early twenty-first century, when the developed world population spends more than 90 percent of the time inside. Epidemiological studies from the 1990s explored the causes of the so-called Sick Building Syndrome (SBS) and the link between the indoor environment in buildings and the health of its inhabitants. The perception of the indoor environment is shifting from the optimisation of individual parameters to a holistic approach, with emphasis not only on the connections between individual aspects of the indoor environment, but also on their relationship to the architectural qualities of the built environment.

KEYWORDS: architecture; indoor environment in buildings; holistic approach to architecture; well-being

INTRODUCTION

One of the primary reasons for building was to create a space “inside”, protected from the surrounding world. The indoor environment in buildings is a set of physical conditions that surround a person and affect their senses [1].
The primary goal of indoor environmental technology is to ensure the health and well-being of its users. Well-being is described as “Such a state of the environment in which people in the intended space feel subjectively the best and are therefore also capable of maximum work performance whether physical or mental, or of resting as effectively as possible. [2]”
The indoor environment consist of several components:

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

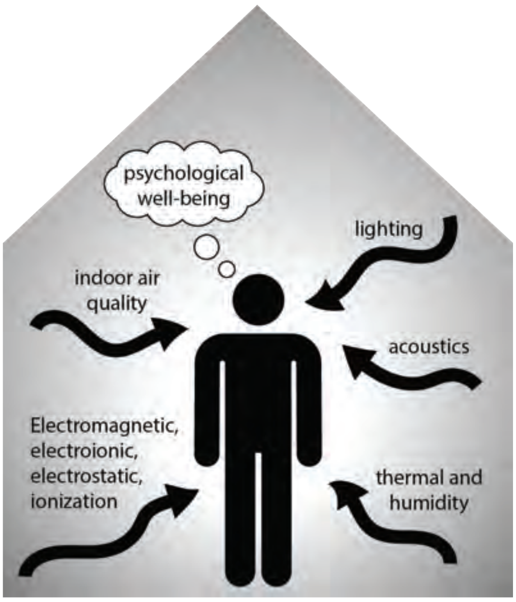

Fig. 1.: Components of indoor environment (Source: adapted from multiple sources)

Determining the quality requirements for indoor environment in buildings has been the task of various professions throughout history, particularly doctors, architects and engineers. This article summarizes how the answer to the question "What is a quality indoor environment?" has evolved, and it also outlines how the builders tried to achieve it.

THE BEGINNINGS OF PERCEIVING THE INDOOR ENVIRONMNETAL QUALITY

The link between the quality of environment inside a building and the quality of life and health of its inhabitants has been recognized in the literature of Ancient Greece and Rome. Hippocrates described the influence of environmental quality (both inside and outside buildings) on human health.
From an architectural point of view, Marcus Vitruvius Pollio addressed some components of the indoor environment in his Ten Books on Architecture in the first century BC [3]. He focused mainly on light and heat-humidity microclimate in buildings.
Vitruvius placed emphasis on daylighting. The artificial lighting was imperfect at the time, as it could only be provided by burning organic materials. In Book VI. Chapter VI. Article 6, Vitruvius wrote:
“We must take care that all buildings are well lighted, but this is obviously an easier matter with those which are on country estates, because there can be no neighbour's wall to interfere, whereas in town high party walls or limited space obstruct the light and make them dark. Hence we must apply the following test in this matter. On the side from which the light should be obtained let a line be stretched from the top of the wall that seems to obstruct the light to the point at which it ought to be introduced, and if a considerable space of open sky can be seen when one looks up above that line, there will be no obstruction to the light in that situation. [3]”
Jan Kaňka from the Faculty of civil engineering of the Czech Technical University published a comparison of this test to the contemporary building regulations in 2014. The results of his calculations justify the belief that the daylighting requirements set out in the current technical standard on daylighting of residential rooms approximately match the notion recorded by Vitruvius [4].
In Book VI. Chapter IV. Article 1 and 2, Vitruvius addressed the appropriate orientation of rooms in terms of the manner and time of day they are used. He emphasised the day-

light quality (“picture galleries, embroiderers' work rooms, and painters' studios (should face the north), in order that the fixed light may permit the colours used in their work to last with qualities unchanged”) and thermal gains (“winter dining rooms and bathrooms should have a south-western exposure”). He also took into account the prevailing winds direction (“books in libraries (with eastern exposure) will not decay. In libraries with southern exposures the books are ruined by worms and dampness, because damp winds come up, which breed and nourish the worms, and destroy the books with mould, by spreading their damp breath over them”) [3].
To a lesser extent, Vitruvius also addressed the indoor air quality, especially regarding the smoke and flue gas exhaust and fresh air supply. He marginally dealt with acoustics, specifically the open air theatre acoustics.
Vitruvius's work was popular even in the Middle Ages and some of the principles contained in it are nowadays still used in construction. The works of renaissance architecture theorists are also based on his legacy. Leon Battista Alberti in his work On the art of building in ten books [5] placed a much larger emphasis on the indoor air quality in comparison with Vitruvius. In Book 1, Chapter 12 (On openings) he established that “Every part of the house should have a window to allow the air within to breathe and be regularly renewed, otherwise it will decay and become stale.” Alberti then went on to recount several histories of plague caused by spoiled air.
Alberti shared Vitruvius’s opinion on daylighting, also requiring that the open sky can be seen from the window openings. He already addressed acoustics in greater detail, although still not in terms of noise protection, but only in terms of sound distribution depending on the shape of the space (especially ceiling).
Andrea Palladio in his Four books of architecture [6] stemmed from the works of both Vitruvius and Alberti. The contribution of his work for the indoor environmental quality lies in demonstrating the individual aspects of the indoor environment on practical examples. In the First book, Chapter XXV. On the dimensions of doors and windows, Palladio first pointed out the interrelations between individual components of the indoor environment (particularly the conflict of daylight and thermal parameters) and the necessity of compromise solutions.
The entirety of Book two is dedicated to the comfort or convenience in private residences. Palladio used the following definition of convenience (comfort) in a house: “for that house only ought to be called convenient, which is suitable to the quality of him that is to dwell in it, and whose parts correspond to the whole and to each other.”

THE 19TH CENTURY

Throughout most of the course of history, thinking about the indoor environment was in the realm of philosophy [7]. The practical solution of the environmental quality of indoor spaces was in the competence of architects. The turning point in the perception of the indoor environment came in the nineteenth century, in the context of a major lifestyle change. In connection with the Industrial Revolution, there was a mass migration to the cities and people began to spend increasing amounts of time inside buildings. The impact of the environment in buildings both for work and housing on human health has thus become increasingly important and has been the subject of medical research.
The link between the indoor environment in buildings and the health of their users was complexly described by Florence Nightingale, an English social reformer and statistician, and the founder of modern nursing. The first chapter of her work Notes on Nursing, What It Is, and What It Is Not [8] focuses not on patient care, but on ventilation. She wrote: “The first task of nursing: to keep the air that breathes the patient as pure as the outside air, without cooling them.” In the second chapter, she mentioned the five essential points to ensure the health of houses: pure air, clear water, efficient waste water drainage, hygiene and light. Florence Nightingale regarded the indoor environment as a complex whole that plays a key role in the health of its inhabitants.
Another turning point in the perception of the indoor environment was the separation of an independent discipline of engineering from architecture, which took place in the beginning of the nineteenth century. It was the engineers who set requirements for some parameters of the individual components of the indoor environment, based on medical knowledge.
For example the requirements on the amount of air for ventilation were established. ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers, formed in 1894) recommended in 1895 as a minimum rate for ventilation 15 l/s per person. This ventilation rate was based on the work of John Billings (1836-1913), medical doctor and the American authority in the field of ventilation at that time [7].

THE FIRST HALF OF THE 20TH CENTURY

In the 19th century, the influence of the quality of the environment in buildings on human health has been proven and the values of some parameters of its individual components have been determined. However, the conditions in the early 20th century cities did not match the idea of a healthy environment.
The quality of life in cities was one of the main themes of the early 20th century architecture theory. Probably the most important document for defining environmental requirements in buildings is the Athens Charter [9], a set of "modern urbanism" principles, adopted at the CIAM conference in 1933, published by Le Corbusier in Paris in 1943. The Athens Charter has become a theoretical basis for functionalist urbanism.
In particular, the following articles are relevant to the quality of the indoor environment:
“Observations:
12. Dwellings are scattered throughout the city without consideration of sanitary requirements.
13. The most densely populated districts are in the least favourable situations (on unfavourable slopes, invaded by fog or industrial emanations, subject to flooding, etc.)
14. Low in density developments (middle income dwellings) occupy the advantageous sites, sheltered from unfavourable winds, with secure views opening onto an agreeable countryside, lake, sea, or mountains, etc. and with ample air and sunlight.
16. Buildings constructed alongside major routes and around crossroads are unsuitable for dwellings because of noise, dust and noxious gases.
17. The traditional alignment of houses along the sides of roads means that good exposure to sunlight is only possible for a minimum number of dwellings.
IT IS RECOMMENDED
23. Residential areas should occupy the best places in the city from the point of view of typography, climate, sunlight and availability of green space.
24. The selection of residential zones should be determined on grounds of health.
25. Reasonable densities should be imposed related both to the type of housing and to the conditions of the site.
26. A minimum number of hours of sunlight should be required for each dwelling unit.
27. The alignment of housing along main traffic routes should be forbidden”
The ideas of the Athens charter were applied in the post-war reconstruction of European cities and in particular in setting the requirements for indoor environment. In the first half of the 20th century, the requirements for the individual aspects of the indoor environment (thermal technology, indoor air quality, luminous and acoustic properties of buildings) were more precisely defined and described. Standards and legislation requiring compliance with some internal environmental parameters have arisen mostly after World War II. These regulations form the base for most of the regulations currently in force.

Thermal technology and ventilation
The research on thermal environment essentially began in the 1920s in the USA, where it was first understood as a so called thermal balance. The researchers used the heat exchange method; a negative thermal exchange means the

environment is too cold and vice versa. To provide comfort, the mean skin temperature must be in certain limits. Later, the adaptive approach, which is based on "the biological insight that the human being is a comfort seeking animal who will, given the opportunity, interact with the environment in way that secures comfort" began to prevail [10].
The perception of thermal technology and ventilation is also linked to the beginning of air conditioning. The researchers were increasingly convinced that ventilation is mainly a matter of comfort and not of health. There was a growing resistance to heating the large amounts of outside air prescribed for ventilation [7].
In the Czech territory, the first standard dealing with the issue of thermo-technical parameters was elaborated in 1954. Criteria for thermal-technical properties of building structures were based on the properties of solid brick masonry of 450 mm thickness [11].

Daylight and insolation

In 1904 the Commission International d'Eclairage (International Commission for Lighting) was founded and began to propose standards and develop the science of photometry. The scientific approach to lighting focused in the beginning on lighting comfort and tasking activities and then slowly shifted towards lighting and health [10].
In the Czech Republic, the first daylight standard was drafted in 1949 [12]. This standard stated that "daylighting should be a) expedient, b) it should be of sufficient intensity, c) uniform across the surface and no dark corners should be formed. The following aspects have a favourable influence on the uniformity of illumination: a) higher positioned windows, b) narrow pillars between windows, c) greater height of the room, d) diffusing material (curtains) in windows, e) light painting on walls and ceiling." The minimum and recommended values of the daylight factor were already established. This metric is nowadays still used to set the requirements on daylight in the Czech legislation. The demands on daylighting in residential rooms were established in 1955 [13].
With the progress in perfecting the artificial lighting, daylight was temporarily deemed less important as a primary source of light for work (especially in administrative buildings).

Acoustics

The first requirements on the acoustic performance of the walls separating apartments were formed in the beginning of the 20th century when the basic physics principle of the building acoustics was formed. The Mass law describes the transmission of airborne sound across a solid wall or a single skin partition. In the Austrian-Hungarian building code, it has since been established that the basis weight of the inter-apartment walls should correspond to at least the basis weight of a solid brick wall of 25 cm thickness [14]. The first normative regulation that mentioned the requirements for permissible noise values was the Czechoslovak State Standard of 1953 [15].

THE SECOND HALF OF THE 20TH CENTURY

The battle for enforcing the requirements for a healthy indoor environment in buildings has therefore been fought and specific requirements have been introduced into the legislation. Practical assurance of the quality of the indoor environment in the buildings became the competence of engineers and technicians in the second half of the twentieth century. While the architects needed to be aware of the existence of these requirements, it was no longer necessary to deal with them in terms of architecture theory. The focus of architecture theorists therefore shifted beyond the mere medical harmlessness of the building. The quality indoor environment of a building also included the ability to perceive the architectural qualities of the building with all the senses.
Steen Eilar Rasmussen in his book Experiencing architecture [16] regarded architecture as an indivisible whole, which "confines spaces so we can dwell in it, creates the framework around our lives."
In Chapter VIII –Daylight in architecture, he pointed out that good light does not mean only much light, it must also create a good contrast and allow the distinction of various surfaces. He considered one sides light to be optimal, because excessive uniformity of illumination flattens the space and makes it difficult to perceive it.
"A more or less concentrated light – that is, light from one or more sources falling in the same direction – is the best in which to see form and texture. At the same time it emphasizes the closed character of a room."
In chapter X – Hearing architecture he wrote that the sounds reflected by a building give us an impression of form and material. Some types of music (mainly spiritual) can only be fully appreciated in certain type of space and they sound flat on a recording.
In the 20th century, ways to change room resonance have been introduced into architectural practice, especially to absorb sound and shorten the resonance period. As early as 50, Rasmussen wrote: "The favourite interior of today seems to be something so unnatural as a room with one wall entirely of glass and the other three smooth, hard and shiny and at the same time with a resonance that has been so artificially subdued that, acoustically speaking, one might just as well be in a plush-lined mid-Victorian interior. There is no longer any interest in producing rooms with differentiated acoustical effects – they all sound alike."
The second half of the twentieth century is characterized by belief in the omnipotence of technology. Fulfilment of the standard requirements for individual parameters of the indoor environment (especially its thermal-moisture component and indoor air quality) was ensured by means of technical equipment. This was often dealt with at the project stage when the building's architecture itself has already been designed.
Another major breakthrough regarding the internal environment in buildings has been brought by the 1970s energy crisis. While previously, the requirements for its individual parameters were primarily driven by the effort to ensure a healthy and comfortable environment, energy saving efforts began to be applied in the second half of the twentieth century. For lighting in buildings, it meant returning to daylight as the main source of lighting. The demands on thermal insulation properties of building structures have increased.
In order to save the energy needed for heating, the limits for fresh air in ventilation have been significantly reduced. In 1973, ASHRAE published the first Standard 62, where the required supply air was set at 7.5 l / s per person. In 1981, ASHRAE adjusted the supply air limits to 2 l/s per person for non-smoking rooms and 10 l/s per person for smoking rooms [7].
In the 1980s, the impact of the quality of the indoor environment in buildings on the health of their residents became increasingly important. Especially in office buildings, there has been a phenomenon of increased incidence of health problems. WHO introduced the term Sick Building Syndrome (SBS) in 1982 [7].
Several epidemiological studies have been carried out during the 1990s, suggesting that the SBS is probably caused by a synergy of several different indoor environmental parameters (mainly those related to indoor air quality) [10]. This implies that indoor environment requirements based on the fulfilment of each parameter individually do not meet the actual needs. The perception of indoor environment in buildings therefore began to shift from the individual aspects toward attempts at a holistic approach. Beside the quantifiable parameters, the holistic approach also takes into account the "soft" parameters, mostly linked to the psychology of users and their behaviour. It is a view in which indoor environment quality is approached in an integrative multi-disciplinary way, taking account of possible problems, interactions, people and effects, focusing on situations rather than single components [10].

CONTEMPORARY PERCEPTION OF INDOOR ENVIRONMENT

At present, the focus is mainly on the interaction between aspects of the indoor environment across different disciplines (in addition to architecture and engineering also medi-

cine, psychology, economics and others). This is also related to the trend of integrated building design, which is supported by the development of digital models and methods for the construction industry.
Architecture theorists warn against reducing the architectural experience and the "flattening" of space that the optimization of indoor environmental parameters can lead to (such as uniformity of illumination, reduced reverberation time, reduced airflow and temperature fluctuations). Juhani Pallasmaa in his book Eyes of the skin, subtitled “Architecture and the senses” [17], represents this point of view on the indoor environment. The first part of the book addresses the dominance of sight over the other senses (ocularcentrism) in the European culture, philosophy and in extension architecture.
The second part is focused on the sensual architecture, it is an overview of the synergies between the senses and the different perceptions of architecture. The author pointed out that evenly lit space is boring and does not cause emotions. “In our time, light has turned into a mere quantitative matter and the window has lost its significance as a mediator between two worlds, between enclosed and open, interiority and exteriority, private and public, shadow and light. Having lost its ontological meaning, the window has turned into a mere absence of a wall.”
Pallasmaa regarded the aural perception of architecture similarly to Rasmussen; “Buildings do not react to our gaze, but they do return our sounds back to our ears.” He was even more acutely aware that the contemporary architecture of the interior and exterior does not allow the perception of space by hearing. “The wide, open spaces of contemporary streets do not return sound, and in the interiors of today’s buildings echoes are absorbed and censored.” Also the omnipresent reproduced music “eliminates the possibility of grasping the acoustic volume of space.”
Pallasmaa required architecture to transcend its functional base, expressing a desire for tension and a contradiction between functionality and uselessness. “Architecture cannot, however, become an instrument of mere functionality, bodily comfort and sensory pleasure without losing its existentially mediating task.”
Ensuring a quality indoor environment has returned to the architect's competence over the past decades. The principles of architectural design that are key to the resulting indoor environment of the building are summarized most comprehensively by Norbert Lechner in his book Heating, cooling, lighting: sustainable design methods for architects [18]. The initial premise of this book is the so-called three-pier approach, where the first stage is the building design itself (its orientation and location, its envelope design, the materials used, the shielding etc.), the second stage are the passive systems using natural energy and to third level are technologies, i.e. active systems.

SUMMARY

The quality of the indoor environment in buildings and its connection with human health and well-being has been acknowledged since the beginning of the history of architecture. First of all, the focus was on the light and heat-moisture components of the indoor environment. The quality of indoor air also played an important role, especially the removal of pollutants and exhaust gases. Acoustics has historically been studied only in terms of spatial sound distribution and noise protection has only become a topic in the nineteenth century. Medieval and early modern theory of indoor environment in buildings was based on the principles established in ancient Greece and Rome, with only partial additions.
The turning point in the perception of the indoor environment in buildings occurred in the nineteenth century, when the population moved to cities in the context of the Industrial revolution, and people began to spend more and more time inside the buildings. The impact of the environment on buildings for work and housing on human health has thus become increasingly important and has been the subject of medical research. At that time, engineering has separated from architecture. Thus, the quality of the indoor environment has become largely a task for engineers and technological equipment.
The modernist movement of the early twentieth century promoted a quality environment (inside and outside buildings) as one of the fundamental human rights. After World War II, legislative regulations were created requiring compliance with certain parameters of the indoor environment. The main criterion for determining these requirements was the health and well-being of users.
In the second half of the twentieth century, ensuring the required quality of the indoor environment in buildings was perceived as a matter of technical building equipment, which was often solved without direct cooperation with the architectural design. The 1970s energy crisis has put an end to this approach. Energy prices have risen dramatically, leading to a reassessment of indoor quality requirements. For some aspects of the indoor environment, allowable limits have been significantly reduced, especially for ventilation and air conditioning, the most energy-intensive system in the building. Thus, the energy performance of the building has become the determining criterion for determining the quality of the indoor environment rather than the health of its users.
In the 1980s, there was a phenomenon of increased incidence of health problems caused by poor indoor environmental quality, for which the term Sick Building Syndrome (SBS) was introduced. Epidemiological studies have shown that the cause of SBS is probably the synergy of various parameters. This has led to the introduction of a holistic approach to the internal environment in buildings, which in addition to individual parameters also deals with their interaction.
Nowadays, designing a quality indoor environment in buildings is returning among the tasks of an architect and is already being addressed in the early stages of building design.

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