CURRENT VENTILATION AND AIR QUALITY PROBLEMS AGAINST HISTORICAL SOLUTIONS

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Abstract
The paper describes the issue of ventilation and air quality in buildings with reference to regular tightening of heating standards. The purpose of the work is to show the risks related to excessive insulation of buildings, which is thought to have a negative influence on users’ well-being and health. The development of issues related to thermal comfort has often led to erroneous solutions. As a result, problems such as “Sick Building Syndrome” and “Building Related Illness” has developed in the recent history, whereas in the long history of the ‘art of construction’, there existed a number of solutions beneficial for users’ health. This issue serves as a pretext for the presentation of former solutions, gradually improved on the basis of the observation of nature, physical phenomena, predecessors’ experiences, creative thinking and intuition. They were used for ages and have become a basis for today’s architectural solutions, although some of them have been forgotten or eliminated by higher and higher normative requirements. In the paper, the author asks the following research question: Do modern legal instruments and standards provide an effective guarantee of high quality of internal air and heat comfort of buildings? Is there an alternative development path for these issues?

Keywords: Air quality; History of architecture; Sustainable construction; Ventilation.

1. INTRODUCTION

The amendment to the Regulation of the Minister of Infrastructure on technical conditions to be met by buildings and their location adopted on 1st January 2014 invites a reflection on the present situation as well as the future of ventilation and air quality issues inside buildings.

Gradual tightening of heat standards has a significant impact on modern architecture. Moreover, excessive insulation is thought to pose a threat to the users' well-being and even health. The development of issues
related to thermal comfort has often led to erroneous solutions. Their results in the recent past included SBS (Sick Building Syndrome) and BRI (Building Related Illness) defined in the second half of the 20th century [15]. After all, in the long history of the “art of construction”, there existed a number of solutions that were beneficial for the users’ health. They have been used for ages, gradually developed on the basis of the observation of physical and natural phenomena, predecessors’ experiences, creative thinking and intuition. Some of the solutions are used as a basis for today’s architectural solutions, whereas other ones have been forgotten or eliminated by higher and higher normative requirements.

The purpose of the work is to confront modern standards and legal instruments with historical solutions. The scope of the discussed issues covers the European architecture, including external influences that are essential for the development of certain systems.

The adopted study method involves: review and analysis of literature on a given issue, proprietary architectural studies included mainly in the doctoral thesis, as well as the range of interest developed as part of the professional and didactic work at the Faculty of Architecture of the Silesian University of Technology [10].

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2. PRESENT SITUATION

2.1. Standards and legal instruments

Currently, there is a number of established standards and legal instruments related to ventilation. The most important regulation concerning the principles of building construction, including ventilation and air conditioning installations, is the Regulation of the Minister of Infrastructure of 12 April 2002 (as amended) on technical conditions to be met by buildings and their location. It establishes all or part of the requirements covered by standards. As far as ventilation is concerned, the most important issue is the amount of air that should be supplied per user of the room. In residential and public utility buildings, 20 m³ of fresh air per hour (30 m³/h/person in rooms without openable windows) should be supplied. The last amendment to the “technical conditions”, applicable since 1 January 2014, concerning mainly heat standards, gave rise to a discussion about the development trends related to these solutions. It is noteworthy that it envisages gradual tightening of the “heat transfer coefficient” and decreasing the annual consumption of the “primary energy” in the years 2017 and 2021. This situation results in the common use of mechanical ventilation systems applying “heat recovery” and thus the departure from the natural ventilation, i.e. a method used since the dawn of time. Moreover, the new document introduces the parameter of “air tightness”, which involves the design and construction of a building in a way to achieve full air tightness. One can say that under such assumptions, the internal air quality is conditioned (at least at the design level) by a mechanical ventilation system. That is why the full responsibility rests on the designer of an integrated system, whereas the proper functioning of an installation also depends on the proper calibration during the phase of launching as well as programming and supervising during the use in an architectural structure.

2.2. Sustainable construction certification systems

Although the standards related to ventilation provide for periodic inspections and servicing of the installation, they do not mention the verification and monitoring of system parameters at the time when a building is used. The situation concerning multi-criteria assessment systems is different. As opposed to the above-mentioned documents, they are applied throughout the whole building’s life cycle, not only during the design phase. Another important thing is that certification systems are addressed not only to industry specialists, but also to investors and persons working in the area of facility administration and management. This aspect is particularly important, but, unfortunately, often pushed into the background of investment management. However, it is proper and conscious facility management that guarantees the fulfilment of the designed parameters of ventilation, heating and air conditioning, which translates directly to the quality of internal area. These activities guarantee heat comfort and users’ health.

Currently in Poland, all three most important green architecture certification systems are available: English BREEAM (Building Research Establishment Environmental Assessment Methodology), American LEED (Leadership in Energy & Environmental Design) and German sustainable construction certificate granted by DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen).
They represent different approaches to internal air quality, but they present this issue more broadly in comparison to standards and legal instruments. DGNB, in the category of “social and cultural aspects”, assesses the internal air hygiene and user control possibilities. BREEAM approaches the topic in a different way, rating, in the “health and well-being” category, parameters such as natural ventilation ability, internal air quality, minimization of volatile organic compounds (VOCs) or non-contamination with micro-organisms. One can say that the focus is on the elimination of risks related to the above-mentioned “SBS”. However, the greatest importance to ventilation and air quality issues is attached by American LEED. In the most developed category, i.e.: “the quality of internal environment”, solutions such as external air supply monitoring, increasing the level of ventilation as well as ensuring and verifying users’ thermal comfort are assessed. A facility having the LEED certificate must strictly obey the requirements concerning the minimum rate of internal air index according to the specifically defined standards and concerning the control of the so-called Environmental Tobacco Smoke (ETS). This means that the total smoking ban or the creation of special areas intended for this purpose in a building is required. Points in this category can also be obtained through the use of health- and environment-friendly construction and finishing materials, such as: glues, leak stoppers, paints and varnishes. This aspect is particularly important as the emission of chemical pollutants in a building is especially hazardous for its users’ health in the context of the probability of the occurrence of “SBS” and “BRI”. That is why the LEED certification system also requires permanent monitoring of internal sources of chemical and pollutant emissions throughout the whole period of the building’s use.

3. HISTORY

The observation of nature and physical phenomena was certainly the source of inspiration for the architectural solutions applied in the past. Nowadays, we can observe an intentional return to these issues in the architecture and other areas of technology (biomimetics, biomimicry) [2]. Mick Pearce, an African architect, is inspired by termites’ structures. Termitary is where one can look for inspiration for natural ventilation. Such a structure is not only based on the air supply by ventilation of the system of internal areas and corridors, but also on an attempt at maintaining a relatively stable temperature and humidity of an interior, in order to ensure optimum living conditions. For similar reason, buildings have been ventilated from the ancient times, through the Middle Ages and modern times.

3.1. From the ancient times until the 19th century

Natural ventilation of interiors based on free airflow through window or door openings was probably the oldest air circulation method in the history of construction. Various full or openwork veils were used for the control of internal conditions. At first, wooden elements and animal skins were used, whereas later – thin translucent marble slabs and, finally, glass. The arrangement of window openings was not accidental either. Maximum air circulation was desirable especially in the hot climate. This solution was applied, for example, in a medieval Castello della Cuba palace in Palermo erected in 1180, where windows are located on the north-east side, in order to capture the fresh and wet sea wind [4].

As far as ventilation development is concerned, the use of chimney draught was a step forward. This was probably related to the development of heating systems. Palladio writes: “the ancients used to heat their rooms in this way: they built fireplaces in the middle with columns or modillions, above which was the pyramidal chimney breast where the smoke went out (...). When they did not want the fireplaces, they built chimneys or ducts (...) in the thickness of the wall through which the heat of the fire below the rooms rose and went out” [9]. Apart from their basic role, heating systems used at that time undoubtedly ensured air circulation in a room [12]. The use of smoke pipes forced air circulation even outside the heating season. In some facilities, parallel flues and hot air distribution lines were used. This solution was applied, for example, in a Cistercian monastery in Lubiąż, where both air channels distributing heat in the interiors of the facility as well as flues connected with hearths have been preserved (Fig. 1). They form a heating system that is difficult to figure out today. Łużyniecka, in her description of an abbatial palace in Lubiąż, a part of the Baroque extension of the monastery originated in 1681, mentions a “well-thought-out heating device”. She calls it a “large wall furnace” [7].
Richie writes that air circulation in buildings is also enhanced by stairwells, which, due to their vertical form and large cubic capacity, make use of the chimney draught [12]. This principle was, in a sense, used in the ancient times in Africa and the Middle East, but it also had influence on European architecture in Sicily. The Egyptian “malqaf”, Iranian “badgir” or “torre del vento” (the tower of winds) used in Sicily are nothing other than an architectural element ensuring intense ventilation and cooling of a building’s interior. There are numerous types of wind towers, from simple roof air intakes (“malqaf”) to complicated structures of high towers (“bagdir”), sometimes connected with a system of underground channels supplying air cooled in a natural way. Often containers with water are used to humidify and cool air. Chimney draught is only one of the elements of these systems – the second, necessary one is the use of wind power. That is why they are called “windcatchers”. In the case of the Iranian solution, a wind tower is vertically divided into two parts and consists of both an air intake and an exhaust. It catches air at the point where it is faster and cooler than at the ground level,
leads it through vertical ducts to the interior of a building, and then throws the warm air out to the other side of a tower in a similar way. According to Fathy, the architecture is closely related to a place, as it uses unique properties and directions of wind [5].

An element of a tower of winds has been applied in a medieval Castello della Zisa palace in Palermo, raised in ca. 1165 by the king of Sicily – Roger I. It is the royal chamber at the top floor of the fortified palace that is called “stanza del vento” – a wind hall [4]. Two centuries of the Arab rule on the island left the influences and architectural solutions that are so perfect that even Norman rulers could not resist them. Some elements of this philosophy were later reflected in the architecture of Italy.

The examples include the Renaissance architecture, in which this line of thinking was continued in the development of ventilation systems. In his Four Books on Architecture, Palladio mentions an outstanding solution that is probably one of the first interior air conditioning systems. He writes about Villa Costozza, a house of Trenti family from Vicenza and “caves (...) which were quarries in antiquity (...) in which very cool winds originate”. As he further writes, owners “direct the breezes to their houses through certain subterranean vaults that they call ventiliducts and then send the fresh air through all the rooms with tubes like those mentioned above, opening and closing them as they like to produce more or less coolness according to the season”. He also writes about an underground chamber in which these “ventiducts” (“ventidotti”) gather, calling it “the prison of the winds” (“carcer dei venti”). This place has been called “Eolia” (Aeolia) by Count Francesco Trento [9].

Palladio’s words are true, and the described system has functioned to this day. In fact, the estate in Costozza di Longare near Vicenza consists of several palaces erected in the “cinquecento” period, i.e. the 16th century, the most impressive one of which is Villa Trento, currently Villa Carli. Probably almost all facilities are connected to this natural air conditioning system. However, the “prison of the winds” described by Palladio is located under the piano nobile floor in Villa Aeolia, the smallest and the most modest facility located at the main composition axis of the solution. There is a stone grillage in the floor. It enables the circulation of air supplied through underground ducts. The air supplied from rock caves has a fixed temperature of 10-12°C throughout the whole year, which ensures natural cooling during the summer and the softening of low temperatures in the winter [11].

Ventilation was therefore not strange to the author of La Rotonda. This is visible in the construction solutions of his famous work (Fig. 2).

Despite the fact that the villa was finished by Vincenzo Scamozzi and the height of the dome and the shape of lamp posts, among others, were slightly modified, we can see a clear reference to the Roman Pantheon, which was called “rotunda” by the contemporaries – as Palladio writes. In his Four Books, he actually presents as many as ten plates with drawings depicting this building, justifying it by the uniqueness of the facility [9]. Palladio himself intended to cover the central hall with a semi-circular dome, whereas Scamozzi lowered it slightly and, according to his original plan, finished it with an open oculus, just as in the Roman prototype [6]. After all, the Pantheon was an inspiration for numerous other architects. It was no accident that the central part of the yet medieval Florence Cathedral, later covered with Brunelleschi’s dome, had a very similar span: 42 m in comparison to 43.4 m in the Pantheon [14]. The uniqueness of the Roman building lies in the fact that it is theoretically possible to inscribe a sphere within its interior, following the curve of the dome. As far as the issues related to ventilation are concerned, very interesting is the eight-metre-high oculus at top of the monolithic concrete dome. Light and rain come in through the hole. The floor is prepared for the channelling of rainwater. However, it is said that in specific conditions, high pressure inside the building does not let the rain in or reduces it significantly.

From the point of view of physics, this is important whether appropriate air supply to the facility is ensured. Scamozzi’s drawings show that this method was used to ensure air circulation in La Rotonda. The air supplied from the underground (base course) storey flew through the interior and escaped at the top of the dome [1], [6].

This principle had also been present in sacral facilities since the Middle Ages. Observing the interiors of Gothic churches, one can notice that vaults on some spans have an openwork keystone resembling the oculus in the Pantheon. Perfect examples of this solution include Gothic churches in Wrocław, e.g. the Cathedral, where such an open keystone is located in the sexpartite vault of the central part of the chancel (Fig. 3), or the Church of Saint Mary on Piasek Island having three vault keystones of this kind. They are located in central points of the nave and chancel (Fig. 4).
Assuming that it was usually impossible to open windows in this kind of facilities, ventilation through vault keystones was the only air circulation route. What is important, it could be regulated by covering the hole with boards. The prerequisite, just like in the previously discussed examples, was to ensure the access of air – through portals in this case. Apart from the positive influence on users, this solution had also a salutary influence on the condition of walls exposed, for many reasons, to dampness. A bit later, in the 18th century, this rule started to be used mainly to the benefit of users, to ensure quick air circulation in theatre and opera auditoriums.

3.2. The 19th century

The industrial revolution period was a landmark for issues related to ventilation. As Borusiewicz writes, in the years 1824–1840 ventilation systems became widespread in France and England simultaneously. At first, they were present only in factory facilities and public utility buildings. The idea was later developed for the purposes of common application in residential buildings. In 1906, an interior air conditioning system was additionally introduced [3]. Innovative concepts, which became a starting point for modern ventilation systems, were used. Interesting solutions for a sacral building are presented by Ritchie in his *Treatise on ventilation* [12]. It is a “roof ventilation” system, as he calls it, in which the supplied air is initially warmed up through the use of double walls. The attic space is a kind of a heat exchanger, where the routes of supply and exhaust air are crossed. This is probably one of the first concepts of the so-called “heat recovery” system in architecture.

It should be mentioned that it was in the 19th century that people started to think in a scientific way about the conditions of residential interiors and their influence on the users. Rapid urbanization, overpopulation and intensive industrial development led to
numerous diseases and epidemics. Growing medical knowledge and the search for effective treatment methods caused that contemporary researchers focused on construction issues. They were interested in the quality of air and ventilation. People sought the sources of numerous diseases in contamination and substances found in the air. Moreover, once the chemical composition of carbon dioxide was known, it was proven that its level has great impact on people’s well-being. These factors caused that in the 19th century Englishmen became obsessed with room airing. All books on the construction of houses published at that time had at least one chapter devoted to ventilation and the so-called “bad air symptoms”. In one of them, published in 1880, Douglas Galton, an English engineer, defines even a room air circulation standard. The value recommended at that time, i.e. 1 500 cm³ per minute per person, was much higher that the standards applicable today [13].

Paradoxically, ca. 100 years later, in 1982, the World Health Organisation officially coined the term “Sick Building Syndrome” (SBS), defining a set of symptoms related mainly to the shortage of fresh air in a room and its poor quality. In this case, the main reason for the existence of these adverse phenomena was the insulation of a building used to reduce heat loss [15].

4. CONCLUSIONS

Taking into account the current complexity of air quality issues, heat comfort and ventilation, one should analyse historical green solutions when searching for alternative ways of development. From the point of view of users’ health, the attempts to return to the strategy of natural ventilation of a facility, supported by advanced technologies and knowledge on the development of sustainable architecture, seem to be very important [8]. Present legal instruments and standards do not provide an effective
guarantee of high quality of internal air and heat comfort of buildings. It is possible to achieve these goals through the development of sustainable construction certification systems. Their broad view of the issues of green construction does not ignore the problem of air quality as well as users’ health and well-being. LEED, BREEAM or DGNB take a different approach to this idea, but they all treat these issues as essential in the process of obtaining a certificate. Thanks to the flexibility and development possibilities of certification systems, it is possible to apply innovative thinking and put historical solutions into practice to the benefit of the future of sustainable architecture. It is essential that the experience has an influence on the development and improvement of applicable legislation and standards.

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