39| Прегледни научни рад
Review paper
doi 10.7251/STP1813536C ISSN 2566-4484

АРХИТЕКТОНСКЕ МЈЕРЕ ЗА ОБЕЗБЈЕЂЕЊЕ КВАЛИТЕТА УНУТРАШЊЕГ ВАЗДУХА У ЗГРАДАМА

Sasa Cvoro, *sasa.cvoro@aggf.unibl.org*
University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy

Abstract:

Рад је фокусиран на значај мјера за обезбјеђење ваздушног комфора у градитељству и могућност њихове примјене у архитектонском пројектовању. Обезбјеђивање адекватног комфора у физичком оквиру директно утиче на здравље и радне способности људи и значајно повећава потрошњу енергије. На обезбјеђење одговарајућег квалитета ваздуха, односно ваздушног комфора унутрашњег простора, отпада између 30% и 40% укупне потрошње енергије у процесу коришћења грађевинског фонда. У раду је посебна пажња посвећена анализи мјерљивих утицајних фактора ваздушног комфора: објективним параметрима квалитета и влажности ваздуха.

Keywords: архитектонски простор, ваздушни комфор, објективни параметри квалитета ваздуха, влажност ваздуха.

ARCHITECTURAL MEASURES FOR FACILITATION OF INDOOR AIR QUALITY IN BUILDINGS

Abstract:

This Paper focuses on the importance measures for facilitation of air comfort in construction and the possibility of its application in architectural design. Facilitation of adequate comfort in physical environment directly affects health and working abilities of people and significantly increases energy consumption. Between 30% and 40% of the total energy consumption is spent in the process of using the construction fund in order to ensure adequate quality of air, i.e. air comfort of the indoor space. In this Paper special attention is devoted to the analysis of measurable factors of impact on air comfort through objective parameters of air quality and humidity.

Keywords: architectural space, air comfort, objective parameters of air quality, humidity.

1. ARCHITECTURE AND AIR QUALITY IN BUILDINGS

Construction of functional architectural facilities mirrors the creative spirit of the architect embodied in the process of design which merges several activities that are intertwined and interact and influence each other directly or indirectly throughout all stages of architectural creation. This process is primarily defined by designing the architectural organization and materialization and shaping of the space. At the same time, successful and good design and implementation of measures for achieving air comfort in buildings is inter alia significant characteristic of such a design process which would make the adequate functionality of the facilities impossible to achieve.

Objective factors that directly affect the quality of air in buildings are determined by human activities, construction materials, technological and installation systems, equipment and furniture, uncontrolled entering of atmospheric air into the inner space and other measurable influences. Provision and maintenance of satisfactory air quality in the architectural space is achieved primarily by natural ventilation, i.e. bringing fresh, atmospheric, external air of the required quality and removal of contaminated, internal air from the inner space. Measures for ventilation should provide a sense of comfort in the space in accordance with the basic architectural characteristics of the facility / function, form, materialization, etc. /. When selecting the measures, all air comfort parameters must be adjusted so that optimum air quality is achieved, depending on the purpose of the space and the activities that take place in it.

In that regard, it is interesting to refer to the air quality study in buildings conducted over the past decade by the National Institute for Occupational Safety and Health /NIOSH is the US Federal Agency responsible for carrying out research and preparing recommendations for the prevention of occupational injuries and diseases /, which resulted in producing an overview of primary sources that affect air quality in the space. According to this study, the main causes of air pollution in the architectural space are:

- Inadequate ventilation - 52%,
- Air contamintion as the result of factors inside the building - 16%,
- Air ontamintion as the result of factors outside the building - 10%,
- Microbiological contamination of air - 5%,
- Air contamination caused by building structures and construction materials - 4%,
- Unknown sources - 13%. [1:4]

Based on these research, the National Institute has proposed three basic strategies that can be used individually or in combination in order to reduce the presence of contaminants in space:

- Natural ventilation and control of air quality parameters,
- Forced ventilation and air filtration,
- Directl removal of sources of contamination from the inner space
- Domestic regulatory framework on achieving satisfactory air quality in buildings is provided in the Rule Book on Energy efficiency in the form of recommendations according to which air quality in buildings is ensured through:
- Architectural measures, and
- Systems for air quality control [2:5]

Recommendations of architectural measures are:

- that the buildings should be designed to maximally use natural ventilation whereas the cross ventilation should be preferred,
- The systems of natural ventilation control should be foreseen in order to avoid the negative feeling of drafta.

It is particularly recommended that the air quality control system should have:

- forced / artificial / ventilation system installed with the prescribed number of exchanges in an hour in places where it is not possible to achieve the required characteristics of the air comfort by natural ventilation,
- bringing fresh air by forced ventilation for the purpsoe of regulation according to the real needs of of the situation in time when beneficiaries are using the space.

All existing standards and guidelines for achieving satisfactory air quality are based on the same assumption that ventilation is necessary in order to reduce air contamination in the area to the level which is acceptable. To that end, the main goals of ventilating architectural spaces are:

- provision of necessary air for human physiological needs,
- removal of smells in the space,
- removal of pollutants in the space,
- regulation of humidity,
- maintaining optimal conditions of heat comfort in different weather conditions / mostly in the summer period /.

In accordance with the aforementioned, ventilation of space may be:

- Natural ventilation / functions on the basis of natural charactersistics of air and its influence parameters /,
- Forced or mechanical ventilation / functions with the assistance of various mechanical devices or systems of force /,
- Combined ventilation / functions as the result of application of passive and active measures /.

The remaining part of the Paper shall analyze the parameters, possibilities and combinations of natural ventilation as the main element of architectural measures for the improvement of air comfort of the space.

2. NATURAL VENTILATION

2.1. MAIN CHARACTERISTICS OF NATURAL VENTILATION

Natural ventilation / also in scientific and professional literature the term in use: Free ventilation [3: 6.15] / means controlled air movement through open windows and doors or through designated holes without the use of mechanical devices of force, as well as uncontrolled air movement through holes that exist due to certain imperfections in the building.

In physical terms, natural ventilation implies the change of air that occur as a consequence of natural characteristics of air due to the difference in temperature or pressure, or due to the air flow [4: 1202]. Stimulating mechanisms for natural ventilation are on one hand, the difference in temperature between the internal and external air and chimney effect / and on the other hand, the difference in pressure due to wind strength / wind effect / on the outer shell of the building. [3: 6.15] Figure 1 shows the ways natural ventilation functions. [5: 100]

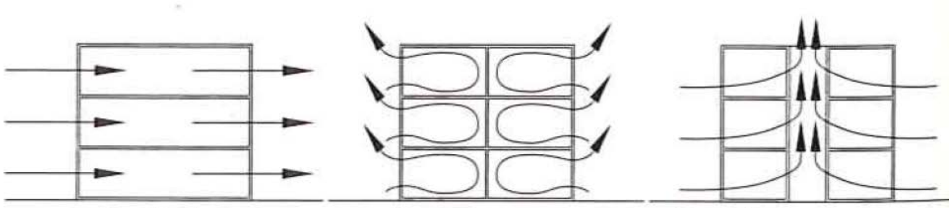

Figure 1. Chart of natural ventilation: 1. Ventilation due to difference in presure / wind effect /, 2. Ventilation due to difference in temperature / chimney effect , 3. Combined ventilation.

The chimney effect is a phenomenon that allows the flow of air through the facility as the result of difference in air temperature between the indoor and outdoor space. Air movement has a vertical trajectory since the density of hot air is lower than the density of the cold air, so the air flow is from downwards up. The wind effect allows air flow through the holes in the building due to the dynamic wind pressure being converted into the static. On the side of the facility exposed to the direct influence of the wind there is a positive pressure difference between the inner and outer space and the negative difference on the side of the curtain, which causes streaming of air in space.

Natural ventilation as a very important and relatively simple technique is intended to contribute to the quality of air in space by reducing the concentration of pollutants, improving the conditions of thermal comfort in space and reducing energy consumption in buildings. The conditions necessary for achieving those improvements in the quality of the environment are:

- the concentration of pollutants in the atmospheric air should be lower than in the indoor space,
- the outdoor air temperature should be within the limits of comfort or in worst case scenario it should not lead to a heat shock for the user of the space,
- Natural ventilation should not cause other environmental and social problems / noise, endangering privacy, etc. /. [6:12]

The quality of air of naturally or partially naturally ventilated building depends largely on atmospheric influences, the microclimatic characteristics of the site, the surrounding natural and built environment and architectural characteristics of the building. With natural ventilation, velocity and direction of the wind are taken into account but also the choice of the appropriate place on the façade of the building where the ventilation openings will be installed. This will affect the amount of atmospheric air that will naturally penetrate into the building and ventilate the room.

In this regard, the quality of natural ventilation depends on:

- Direction and strength of the wind,
- Geometry of the building,
- Surrounding built environment,
- Indoor and outdoor air temperature,
- Type and degree of the porosity of the outer shell of the building. [7:73]

The influence of the wind on the building and the quality of natural ventilation is of highest importance. In the summer period, it has a beneficial cooling effect and reduces the need for forced ventilation, while in other periods of the year and especially during the heating season it significantly increases thermal losses due to higher speed and increased infiltration through the holes and outer envelope of the building. Buildings should be designed to provide access to the breeze that cools the air in the summer, while reducing the cold effects of the wind in other seasons. [8:58]

Application of measures and system solutions to natural ventilation can significantly affect the living standard of the users of the space. The quality of the building as well as the types of energy, services and systems in the buildings define the role of natural ventilation in accordance with the required air quality in the space. Natural ventilation is sometimes not sufficient in relation to the requirements imposed for certain premises, for example, whether it is a matter of a large number of people being in space or a particular process that takes place in the area concerned.

Natural ventilation, in addition to all its good characteristics referred above also brings certain shortcomings:

- could significantly increase the need for heating under certain conditions,
- causes lack of humidity in the winter time,
- too high temperatures in the rooms in the summer period,
- occasionally leads to appearance of the draft with strong winds,
- occasionally leads to inadequate removal of pollutants in the absence of wind. [7:66]

The oldest way of natural ventilation is through uncontrolled openings, i.e. infiltration, while in most cases it occurs when openings are opened / windows, doors, etc. / on the façade and the roof and provides the best effects of circulation and / or air flow in the room. Channel ventilation, also one of the basic modes, works on similar bases. Today, other contemporary forms of natural ventilation are present, such as, for example, horizontal ventilation through openings, chimney effect, double façades etc.

The main forms or the ways of natural ventilation which will be especially discussed in this paper are:

- Infiltration,
- Ventilation through openings,
- Channel ventilation.

2.2. INFILTRATION

The entry of atmospheric air into the room through unintentional openings / gaps, openings in joints, cracks in walls, floors and ceilings, around the windows and doors / is called infiltration. Infiltration is a natural process that could not be fully controlled in conventional building systems characteristic for the period until the end of the twentieth century and used to be one of the primary ways that caused more or less air flow in space. Thus, by the mid-twentieth century due to the low cost of energy and the need for intensive air exchange, infiltration could almost completely ensure adequate air exchange in the space. In buildings with classic materialization systems in the winter period, the number of air exchange in the space ranged from 0.3 to 0.8 h-1. Contemporary building systems strive to achieve the best thermal characteristics of elements and constructions and air tightness, so the air exchange is below 0.1 h-1.

Modern architectural practice has adopted a number of measures in accordance with the regulations on energy optimization which reduce the possibility of air infiltration to the smallest possible extent in order to save energy, reduce heat losses and avoid moisture formation due to atmospheric precipitation based on the collection of the rose through the insulation in the outer envelope of the building. Therefore, infiltration of air through cracks

in modern buildings designed on the principles of energy efficiency have almost no effect on the ventilation of space.
The rate of air exchange caused by ventilation in cracks is increasing as the temperature gradient increases between the indoor and outdoor air temperature as well as with the increase in wind speed. For that reason it happens especially in winter months that there is excessive air exchange while during the summer months the minimum of hygienically necessary air exchange cannot be reached. Even more important than energy losses is, however, the input of moisture through the collection of dew in the construction when the warm and humid air from the room flows outside through the insulation of the shell. [3:6.15]
The tests found that almost all construction materials are porous and that air leaks. The intensity of the porousness depends on the pressures and the air temperature, the thickness of the layer and the type of material. The water content in structures and materials makes them watertight. Also, the water tightness of the structures and especially the interior surfaces is increased by applying paint / oil based paints almost completely do not let air. Table 1 gives a comparative tabulation of the air infiltration through certain different types of structures and materials. [10:195]

Table 1. Overview of air inflitration by various types of structures and materials

Type of structure	Air infiltration l/h
Gap beneath the door 100/5 mm	54 000
Wooden wall, 10 cm thick	1 100
Roof tiles	720
Keyhole	594
Brick wall, 38 cm thick	280
Concrete	5.5
Brick wall, 6.5 cm thick	4.25
Concrete	0.26

2.3. VENTILATION THROUGH OPENINGS

Ventilation through openings or window ventilation means the exchange of air caused through openings / by opening windows, doors, ventilation openings on the façade, roof extensions, etc. / in the level of the outer envelope.
Ventilation through openings is primarily applicable in areas used by relatively few number of people and with no significant air pollution. The efficiency of the ventilation depends directly on the shape, size and position of the holes on the façade and / or the roof. Ventilation through the openings is relatively quick exchange of the entire air in space but at the same time it is hard to determine the actual speed of external and internal air exchange. The most important parameter of the effect on the achievable air exchange velocity is the position of the opening, i.e. the ways of opening.
In relation to the proper layout, the position and the corresponding surface of the openings, the border cases of setting the openings on the façade and their influence on the ventilation of the space are defined:

- With a low-hole opening located in the central part of the wall surface due to the very small difference in air temperature near the neutral axis, there is no air exchange, / Fig. 2.a. /
- With a low-hole opening located in the upper part of the wall surface, due to the displacement of the neutral axis upwards, the pressure increase and permeability of the opening due to the imperfection of the installation there will be certain air exchange, / Fig. 2.b. /
- With a low-hole opening located in the lower part of the wall surface, due to the displacement of the neutral axis downward, outside the zone of maximum pressure, there is relatively low air exchange, / Fig. 2.c. /
- With a low-hole opening located in the lower and upper part of the wall surface due to the position of the neutral axis in the center and the slots of relatively similar heights in the highest pressure and thrust zones, the best air exchange occurs, / Fig. 2.d. /
- With openings positioned with the entire height of the wall surface due to position of openings in the zones of the highest pressure and buoyance, as in the previous case, there is a very favorable air exchange, / Fig. 2.e. / [11: 8]

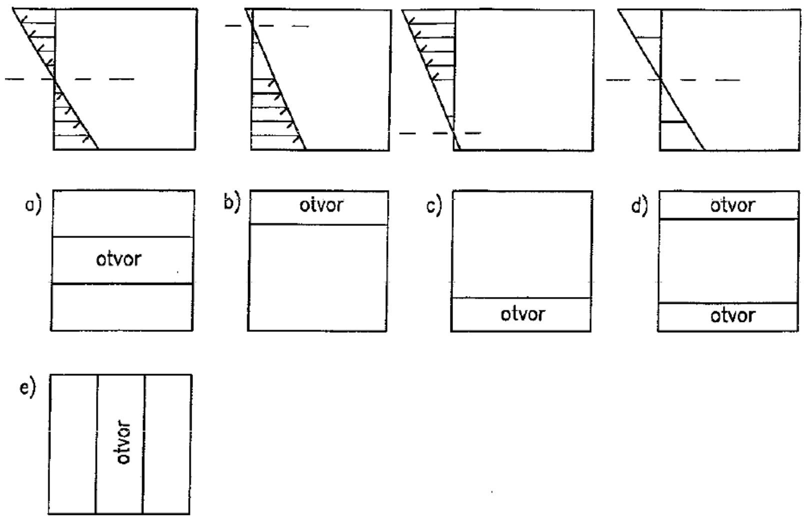

Figure 2. Impact of the position and size of windows on ventilation

In accordance with the way of opening / opening time intervals / there are:

- Impact ventilation / brief opening of the opening /,
- Permanent ventilation / permanent openings [4: 1202].

Impact ventilation is suitable for short-term, relatively fast air regeneration in the winter period with higher temperature differences between the outdoor and indoor air. In this case, when the atmospheric air is significantly cooler than the air in the room, even when there is no wind effect, the atmospheric air flows into the space through the lower part of the opening and leaves the space through the upper part of the opening. / Figure 3. /

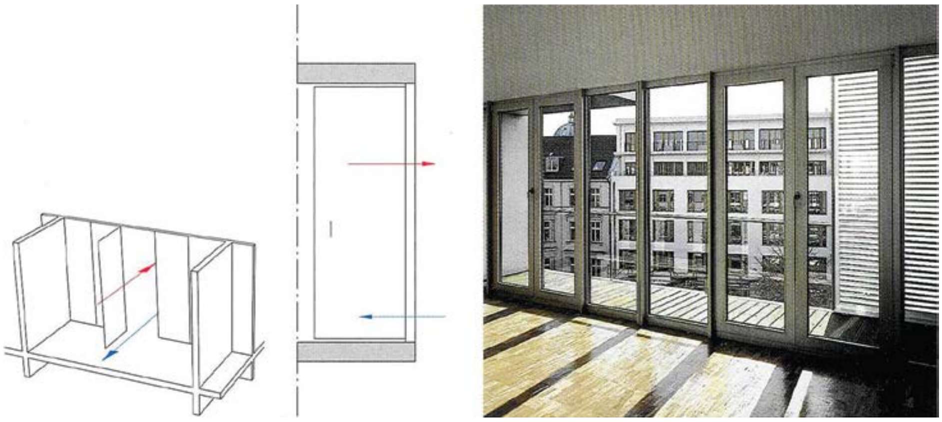

Figure 3. Window ventilation, openings set all over the height of the facade, Residential business building, Gruntuch Ernst, Berlin, 2001

Permanent ventilation is characteristic for the summer period which due to the low temperature differences between the outdoor and indoor air depends to a large extent on the influence of the wind. For permanent or continuous ventilation of space, in contrast to impact ventilation, small openings are preferred, which by correct positioning with the application of the automatic opening and winding system prevent large heat losses, that is, the gain and negative effects of meteorological conditions.

The intensity of natural ventilation depends directly on the orientation of the building. The most common cases, especially for public buildings, are one-sided and two-sided orientation of the space. In the case of one-sided ventilation of the space thermal use is maximized using two openings with as large a vertical distance as possible. In cross-ventilation, the effective use of a thermal buoyance between inlets and outlets of the air is also achieved with as large a vertical distancing as possible. / Figure 4. /

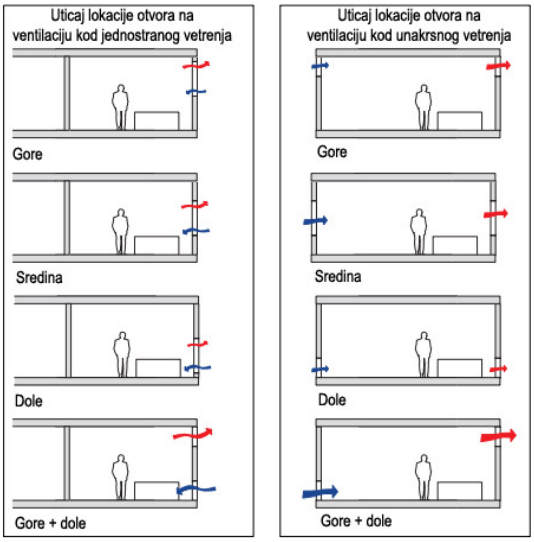

Figure 4. Natural ventilation intensity in a single and double-oriented buildings

The exchange of outdoor and indoor air according to the principle of cross-ventilation is, under realistic bordering conditions, between 50% and 75%. Taking into account the climatic conditions, for complete air exchange in the winter period it takes about 4 to 6 minutes of ventilation and in the summer period in case of inadequate thermal insulation of the building, about 25 to 30 minutes. If a 75% exchange rate is set aside for the ventilation process, then during the winter period, 60 to 90 minutes should last to achieve the minimum required air exchange rate of 0.5 h-1 to 0.8 h-1. In this way, proportionally low heat loss during the day is provided while at the same time good air quality in the room is obtained. By exchanging air through the openings in the night time when, for understandable reasons, the use of permanent ventilation with the opening mode of the window is mainly used, there is often an increase in air pollution, that is, the increased concentration of SO2. [3: 6.17] Table 2 gives an overview of the value of the air exchange coefficients for different of openings. [4: 1203]

Table 2. Overview of the values for feasible coefficient of air exchange with different positions of the openings

Position of the opening	Air exchange velocity / h-1 /
Closed opening	0.0 – 0.2
Tilt and turn windows	0.3 – 3.0
Half open windows	2.0 – 10.0
Completely open windows	5.0 – 15.0
Opposite windows and doors opened	до 40.0

Ventilation through the ventilation holes on the facade works with the constant supply of atmospheric air. During the summer period ventilation is carried out through the opening at the bottom of the wall where the cooler air enters the room and during the winter period ventilation is carried out through higher openings which prevents the entry of cold and humid air with the possibility of regulating the size of the opening. The inlets of fresh air into the building are oriented directly in the direction of the most intensive wind and the outlet is on the roof or on the façade level, contrary to the direction of the supply of outside air.

Special natural ventilation openings are the roof extensions. Ventilation of the space through roof overlays, roof windows or air drainage holes on the roofs of buildings is based on the principle of thermal buoyancy, i.e.when it stagnates at the temperature difference between the outdoor and indoor air. For this ventilation to operate, it is important to bring the atmospheric air that subsequently flows in space when windows and doors are opened.

2.4. CHANNEL VENTILATION

Channel ventilation is applied in cases when the space is located in the central part of the building and when there is no possibility of direct, window or natural ventilation. It operates on the same principles as ventilation of openings, i.e. on the difference in atmospheric and air temperature in the room. The minimum difference in outdoor and indoor air temperatures is unfavorable for air flow and, therefore, ventilation is 5 °C.

With the channel ventilations, a greater air exchange is achieved in the winter period by connecting the air outlet from the room to the window, or the channel that exits to the roof or facade. The buoyancy in the channel grows in proportion to the height, so that there is bigger subpressure / chimney effect/ in the area.

Suitable openings for the supply of outdoor air with sufficient temperature difference, satisfactory air exchange in the space is achieved. When the outdoor and indoor air temperatures are the same, there is no air movement and in cae outdoor air temperature is higher, the direction of movement is reversed with the possibility of entering warm air through the channel into the room. [4: 1204]

As part of the system solution, channel ventilation involved the use of separate inlet and outlet ducts which are designed and run as single and / or assembly circuits. Domestic building practice has shown that for the natural ventilation of indoor space without windows, the inlet channels of atmospheric air without the use of mechanical air conditioning devices are inapplicable, i.e. that the supply of cold outside air during winter times can cause a feeling of discomfort in space and heat losses. Also, these channels leave the possibility due to the lack of adequate outdoor air and treatment of the same, the supply of contaminated outdoor air into the indoor space.

The channel ventilation system functions as a semi-organized system and modern forms of decentralized ventilation enable organized preparation, insertion and regulation of air in the area with the exhaust of by natural means.

2.5. HYGIENIC - HEALTH ASPECT OF VENTILATION

Ventilation of space is necessary to maintain the normal functions of the human body of persons living and working in those areas. Hygienic and health significance of ventilation consists in maintaining air space comfort at the required level.

Ventilation enables from the health aspect sufficient provision of oxygen for normal functioning of the human body, reduces the concentration of SO2 in space, reduces relative humidity, provides physiological heat transfer, removes unpleasant smell, toxins, gases, microorganisms and pathological bacteria. Among the pathogenic bacteria there are Streptococcus salivarius, Streptococcus beta haemolyticus, Staphilococcus, Pneumococcus, tuberculosis and eggs of pinworm. [12:96]

In case of insufficient ventilation, there are negative consequences, i.e. functional damage, superficial breathing, decrease in productivity, etc. Air flow has several positive effects: its dynamic effect stimulates nerve endings in the skin, tones the vascular and neuro system and causes a pleasant subjective feeling. In case of disturbance of optimum airflow, the human body activity can be reduced and functional disorders, respiratory and viral diseases may occur. In case of complete absence of ventilation, it is possible that disorder of thermoregulation of the human body occurs. In the absence of airflow, susceptible persons feel as if they are choking and adversely affect the general heat exchange of the body. Most authors who deal with this topic consider optimal air velocity in space from the hygienic-health aspect, 0.1 m / s. [12:95]

To perform optimum functions of the human body, it takes about 900 l / min of fresh air, while the smallest physiological limit is 210 to 300 l / min per person. The required amount of fresh air is different for space with different purposes. / Table 3. /

Table 3. Amount of air per person in l / min for different types of space

Quantity of air per person in a l/min	Type of space
140 - 280	Rooms with high ceilings, rooms with no smoke, banks, theatres, cinemas, temples, auditoriums.
280 - 420	Housing units, hotel rooms, barber shops, rooms with equipped with light furniture.
420 - 560	Hospitals, restaurants.
560 - 840	Study rooms, offices, rooms with a lot of smoke.
840 - 1040	Conference halls, bars, smoking areas.

As the consequence of inadequate air quality, certain hygienic and health problems appear in modern architectural facilities primarily related to the characteristics of the applied ventilation systems. This primarily refers to the internationally accepted term, so called / Sick Building Syndrome - SBS/, with difficulties that arise and are primarily characteristic for modern public, mostly administrative and business buildings. Symptoms are unspecific and can be seen in a large number of people in a variety of life situations and because of their temporary characteristics are often not considered as direct illness. It is a collective phenomenon and as such can be qualified. There is a suspicion of the existence of symptoms when more than 20% of people have difficulty or when more than 30% of people complain about the problems of the central nerve system. [4:98]
Possible causes of sick building syndromes are:

- Excessive air flow rate or turbulent air supply to the room,
- Difficulties because of microbial allergens and cellular toxins,
- Defects in field of thermoregulation due to lower or higher air temperatures ,
- Low frequency noise interference / <100 Hz / with central ventilation systems,
- Dispersion of smell from humidifiers and filter sections of central ventilation systems. [7:41]

Table 4. Different Difficulties of Sick Building Syndrome and Possible Causes

Sick Building Syndrome	Possible causes
Draft, inclination to cold, rheumatic difficulties.	Excessive air flow rate, too strong turbulence, insufficient air inflow, too low air temperature.
Irritation of skin, upper respiratory tract and eyes, feeling of dry air.	Microbial allergens / from air conditioners /, home dust, mites.
Fever, difficulties with breathing, pain in the joints, fatigue.	Microbial cell toxins / endotoxins, cytotoxins /, water humidifiers, filters and air exhaust components.
Fatigue, difficulties to concentrate, lack of orientation, headache.	Interference with thermoregulation, low frequency sound, allergens, endotoxins, cytotoxins, insufficiency.

Inadequate air quality.	Odor from air conditioning / technical or microbiological /, insufficient effective air exchange.

The sick building syndrome is characteristic for buildings with total or partly central air preparation that have a significantly higher number of air exchange (> 2 l / h) than conventional buildings with natural ventilation / between 0.5 and 1.0 l / h /. [4: 1204] Numerous studies show that naturally ventilated or occasionally naturally-ventilated buildings cause the least number of disturbances and symptoms of sick building syndrome. A specific form of sick-building syndrome appears in modern facilities where no active ventilation measures are applied. This problem is formally called Tight building Syndrome. Insufficient ventilation / <0.5 l / h / leads to increased concentration of pollutants, nowadays especially various allergens / it is assumed that up to 30% of the modern world population suffers from allergic diseases /, and is successfully resolved by measures of decentralized ventilation of space.

3. CONCLUSION

Air comfort in buildings is one of the basis for planning and designing modern architectural buildings. The provision of air comfort as well as the reduction of negative microclimate effects and the concentration of air pollutants to human health constitute concrete goals arising from the basic settings of the architectural design process and the application of energy, environmental and economic optimization measures.

In this Paper the emphasis is placed on the analysis of architectural measures for the provision of the air comfort of the building. The quality of air in the room is determined on one hand by the quality of the atmospheric air supplied and forms of ventilation and on the other hand, by contamination conditioned by the purpose of space and human activities that take place in it. The movement of air in the space is carried out in accordance with the architectural organization of the space. The aim is to provide a harmonized flow of air in the room with the removal of contamination caused by men who stay and work in the indoor space.

On the other hand, energy-saving construction has a constant need to minimize heat losses caused by ventilation. Air exchange is controlled through hygienic criteria and limits of air quality in indoor spacer. Air quality is appreciated in terms of physiologically desirable air properties and a sense of comfort in space. The air quality in relation to the air composition is characterized by a sufficiently high content of oxygen and the smallest possible content of SO_2 as well as other pollutants in the air. Providing sufficient amount of atmospheric air through natural ventilation is necessary to eliminate the harmful effects of pollutants / recommended at least 30 m^3 / h per person /.

In addition to all of the above, energy savings between 20 and 50% can be achieved with the application of measures which specifically refers to the improvement of air comfort. Under the current best practices, the following have proved to be extremely effective:

- optimization of the number of people in the indoor space,
- significant improvement of air tightness of the outer envelope,
- improvement of functional and energy performances of natural ventilation openings,

- natural ventilation with modern forms / night ventilation with thermal mass cooling, interior courtyard concept, vertical channels or two-layer facade systems/,
- controlled and decentralized ventilation with air filtration and high heat energy return coefficient,
- automatic regulation of the opening of the outer openings integrated with the central electronic management system / so-called intelligent building /,
- control of the concentration of SO2 in the air of the indoor space. [13]

LITERATURE

[1] „AE 310 Fundamentals of Heating, Ventilating, and Air-Conditioning“. Brussels, 2005.

[2] Pravilnik o energetskoj efikasnosti zgrada, Beograd: Službeni glasnik Republike Srbije, 2011.

[3] V. Vilems, K. Šild, S. Dinter, Vieweg građevinska fizika: priručnik, I deo. Beograd: Građevinska knjiga, 2008.

[4] H. Reknagel, E. Šprenger, E.R. Šramek, S. Čeperković, Grejanje i klimatizacija. Vrnjačka Banja: Interklima, 2011. M.

[5] Hegger, M. Fuchs, Th. Stark, M. Zeumer, Energy Manual – Sustainable Architecture, Munich: Edition Detail, Birckhauser, 2007.

[6] C. Ghiaus, F. Allard, Natural Ventilation in the Urban Environment - Assessment and Design, London: Earthscan, 2005.

[7] K. Danijels, Tehnologija ekološkog građenja. Beograd: Jasen, 2009.

[8] M. Pucar, M. Pajević, M. Jovanović Popović, Bioklimatsko planiranje i projektovanje: urbanistički parametri, Beograd: Zavet, 1994.

[9] A.G. Kwok, W.T. Grondzik, The Green Studio Handbook – Environmantal Strategies for Schematic Design, Oxford: Architectural Press, 2007.

[10] M. Radonić, Grejanje i vetrenje, Beograd: Građevinska knjiga, 1972.

[11] S. Stanković, Prozori i vrata, Beograd: Arhitektonski fakultet Univerziteta u Beogradu, 1998.

[12] V. Kosorić, Ekološka kuća, Beograd: Građevinska knjiga, 2008.

[13] S.B. Čvoro, „Istraživanje obrazaca za unapređenje vazdušnog komfora prostora u cilju energetske efikasnosti zgrada“, Doktorska disertacija, Banja Luka: Arhitektonsko-građevinski fakultet Univerziteta u Banjoj Luci, 2014.