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Kakovost zraka v prostoru - vzrok za zamenjavo toplovodnega s toplozračnim sistemom ogrevanja

The Indoor Air Quality - The Reason for Replacement of Water-Heating System by Air-Heating System

VINCENC BUTALA

Človek preživi povprečno že 90 odstotkov svojega časa v zaprtih prostorih, postal je ujetnik lastne civilizacije. Za dobro počutje in zdravju neškodljiv notranji zrak je treba v delovne in bivalne prostore dovajati svež, zunanji zrak. Z učinkovitim prezračevanjem, ki povezuje koncentracijo onesnaženja v odpadnem zraku (v prostoru) in koncentracijo onesnaženja zraka v coni dihanja, se raba energije za ogrevanje in/ali hlajenje povečuje. To pomeni, da sta si z vidika rabe energije, kakovost zraka in raba energije v nasprotju.

Ključne besede: prezračevanje prostorov, kakovost zraka, ogrevanje toplovodno, ogrevanje toplozračno

People nowadays spend 90 % of their time in closed spaces, so that they became almost prisoners of their own civilization. But it is necessary to let fresh air into working and dwelling places if we want to feel well and breathe air that is not of a decterious quality. The use of energy for heating and/or cooling rises with the effectiveness of ventilation that connects the concentration of pollution in the waste air (in the space) and the concentration of the air-pollution in the zone of breathing. And that means that the air-quality and the use of energy conflict.

Keywords: ventilation, indoor air quality, water heating systems, air heating systems

0 UVOD

Energijska kriza v začetku sedemdesetih let je botrovala miselnosti, da je treba za vsako ceno varčevati z energijo. Zaradi tega je bila zmanjšana intenzivnost prezračevanja prostorov ob hkratni povečani kakovosti gradnje objektov glede večje zračne tesnosti. Ugotovljene in prepoznavne so bile prve resne zdravstvene težave zaradi poslabšane kakovosti zraka v zaprtih prostorih [1] in [2].

Pri nas je bila sprejeta Resolucija o strategiji rabe in oskrbe Slovenije z energijo [3]. Poleg doseganja dolgoročne zanesljivosti in zadostnosti oskrbe z energijo je njen strateški cilj, ob povečanju energijske učinkovitosti in čim manjšem tveganju za okolje in prostor, tudi skrb za zdravje ljudi. To pomeni, da energijska učinkovitost in/ali učinkovita raba energije ne smeta biti doseženi v škodo ugodja, človekovega zdravja oziroma kakovosti zraka v prostorih [4] ,[5] in [12].

1 KAKOVOST ZRAKA

Za obravnavo problema slabe kakovosti zraka v zaprtih prostorih je znan izraz sindrom "bolne" stavbe. Že leta 1982 je svetovna zdravstvena organizacija (WHO) opredelila pojem sindroma

0 INTRODUCTION

The energy crisis at the beginning of the seventies made people think that it was necessary to save energy at any price. This led to a reduction of space ventilation intensity where there was at the same time an increase in the quality of building construction with respect to greater air tightness. The first of impaired health from poor air quality were diagnosed [1] and [2].

The Resolution about the strategy of use and energy supply in Slovenia [3] support the increase in energy efficiency with a low risk to the environment while being acceptable for the health of people. That means that should not compromise the indoor air quality or people's health [4] , [5] and [12].

1 THE AIR QUALITY

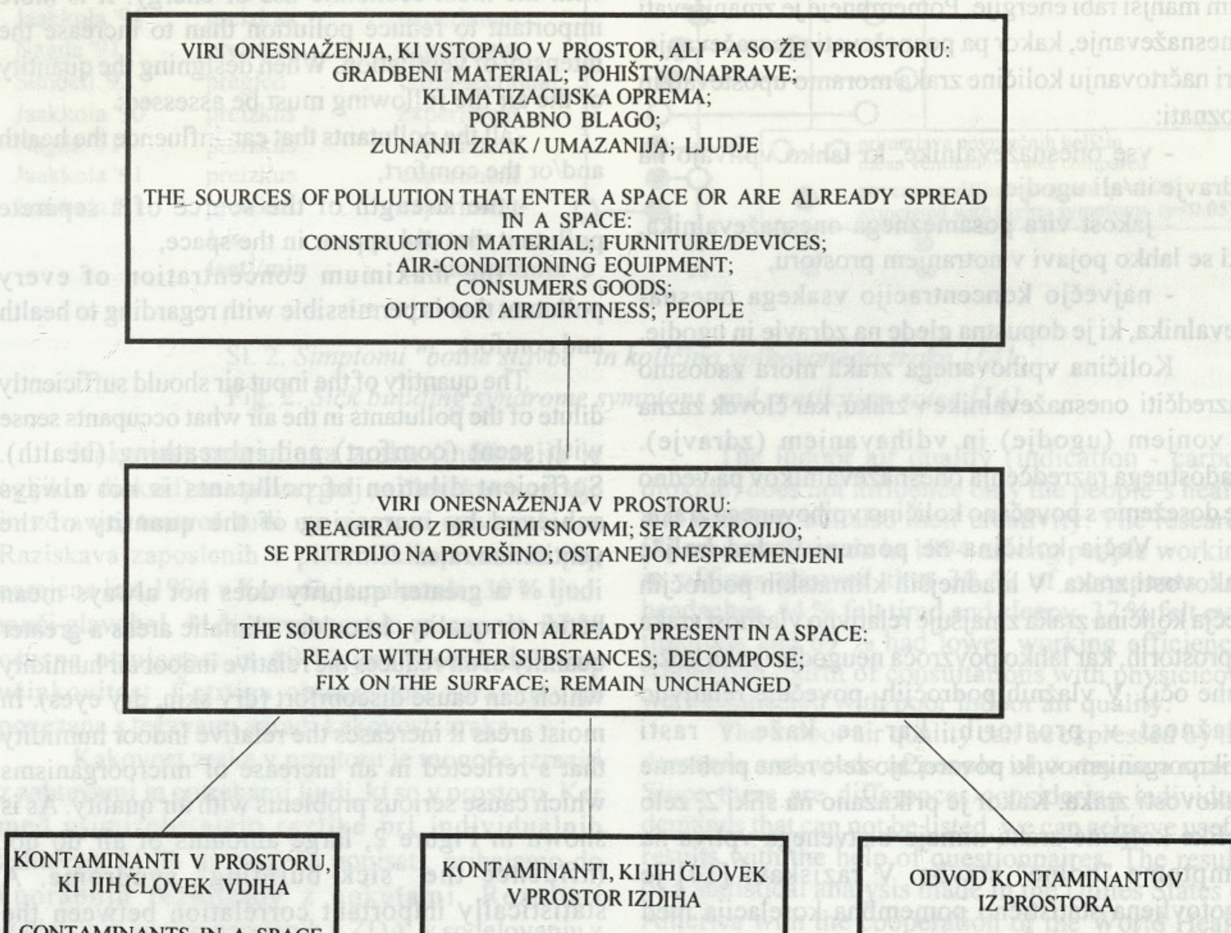
The expression "Sick Building Syndrome" is known when dealing with the problem of bad indoor air quality. The World Health Organization defined the notion "Sick Building Syndrome" already in 1982, first of all due to numerous complaints and number "bolnih" stavb, predvsem s številom pritožb oziroma številom obolelih ljudi v določenem poslopju. V osnovi izjava WHO določa, da je kakovost zraka v prostoru neustrezna, ko 20 odstotkov ljudi občuti zdravju škodljiv vpliv, ki ga je klinično sicer težko ugotoviti. Simptomi, ki se običajno pojavljajo, so raznovrstni. So odziv organizma na trenutno neugodje in razmeroma hitro minejo, ko človek zapusti takšen prostor. Intenzivno in dolgotrajno bivanje v neprezračevanih prostorih lahko privede tudi do akutnih in celo kroničnih obolenj. Omenjena spoznanja so privedla do drugačnega razumevanja kakovosti zraka v prostoru, spreminjajo se standardi in predpisi, obnavljanje notranjega zraka z zunanjim zrakom dobiva vedno večjo veljavo in pomen.

Kakovost zraka v prostoru je odvisna od kakovosti dovedenega zraka, oblike in ureditve prostorov v objektu, načina prezračevanja oziroma klimatizacije in njihovega vzdrževanja ter jakosti in koncentracije notranjih virov onesnaževanja (sl. 1). Pomembni so tudi drugi dejavniki notranjega okolja: temperatura in vlažnost zraka, osvetljenost itn.

of people becoming sick in a defined building. The declaration of the World Health Organization basically defines that the indoor air quality is unsuitable when 20 % of occupants have sensible of symptoms harmful for health that are clinically difficult to diagnose.

The symptoms that usually take place certain are diverse. They are the response of the body to momentary discomfort and are relatively of short duration when a person leaves such a space. Intensive and long staying in spaces that are not ventilated can also lead to acute and even chronic illness. This has led to different understanding of the indoor air quality; the standards and the rules are changing, and the exchange of the indoor air with the outdoor air is considered to be of increasing importance.

The air quality depends on the quality of the inlet air, the shape and the arrangement of the spaces in a building, the mode of air-conditioning, and on its maintenance, the strength and the concentration of the indoor sources of pollution (Fig. 1). Other important factors of the indoor environment are temperature and the air-humidity, lighting etc.



Sl. 1. *Potek onesnaženosti zraka v prostoru*
Fig. 1. *The course of air pollution in an area*

Pri prezračevanju in vrednotenju količine zraka je treba ločeno upoštevati dve komponenti:

- razredčenje onesnaževalnikov, povzročenih zaradi ljudi in njihovih aktivnosti,

- razredčenje onesnaževalnikov, povzročenih zaradi uporabljenega gradbenega materiala, pohištva in vgrajenih sistemov ogrevanja, hlajenja in prezračevanja oziroma klimatizacije.

Sveži zrak običajno nima bistvenega vpliva na kakovost zraka v prostoru, saj je zrak v poslopju tudi do 10-krat bolj onesnažen. Ocenjena občutena stopnja onesnaženosti, ki nastaja v prostoru, je pri običajno grajenih poslopjih med 0,3 do 0,5 olf/m^2 poda (pisarne, učilnice, dvorane). Pri prijetno zasnovanem notranjem okolju, z majhnim virom onesnaževanja zraka, pa med 0,05 in 0,1 olf/m^2 poda [7].

Namen prezračevanja prostorov je zagotoviti kakovost zraka z majhnim tveganjem za zdravje in sprejemljivim ugodjem za ljudi, ki so v prostoru, ob čim manjši rabi energije. Pomembneje je zmanjševati onesnaževanje, kakor pa pospeševati prezračevanje. Pri načrtovanju količine zraka moramo upoštevati in poznati:

- vse onesnaževalnike, ki lahko vplivajo na zdravje in/ali ugodje,

- jakost vira posameznega onesnaževalnika, ki se lahko pojavi v notranjem prostoru,

- največjo koncentracijo vsakega onesnaževalnika, ki je dopustna glede na zdravje in ugodje.

Količina vpihovanega zraka mora zadostno razredčiti onesnaževalnike v zraku, kar človek zazna z vonjem (ugodje) in vdihavanjem (zdravje). Zadostnega razredčenja onesnaževalnikov pa vedno ne dosežemo s povečano količino vpihovanega zraka:

- Večja količina ne pomeni vedno boljše kakovosti zraka. V hladnejših klimatskih področjih večja količina zraka zmajšuje relativno vlažnost zraka v prostorih, kar lahko povzroča neugodje (suha koža, suhe oči). V vlažnih področjih povečuje relativno vlažnost v prostorih, kar se kaže v rasti mikroorganizmov, ki povzročajo zelo resne probleme kakovosti zraka. Kakor je prikazano na sliki 2, zelo velike količine zraka nimajo bistvenega vpliva na simptome "bolne" stavbe. V raziskavi [14] je ugotovljena statistično pomembna korelacija med količino vpihovanega svežega zraka v pisarniške prostore in simptomi "bolne" stavbe: pri vpihovanju 10^{-2} m^3/s na osebo svežega zraka je bilo več pritožb oziroma "bolezenskih" znakov, kakor pri manjši vpihovani količini zraka.

When considering ventilation and the air quality it is necessary to consider two components separately:

- the dilution of the pollutants emitted by people and their activities,

- the dilution of the pollutants emitted by building using the construction material, furniture and the inbuilt systems of heating, cooling and ventilating/air conditioning.

Fresh air usually does not have any influence on the indoor air quality since the air in a building can be to ten times more polluted. The estimated perceived degree of pollution that is spread over the room, is, with classically built building, between 0,3 and 0,5 olf/m^2 of the floor. With the inner area well designed the perceived degree of pollution is 0,05 and 0,1 olf/m^2 of the floor [7].

The purpose of ventilating spaces is to ensure the air quality constituting a low health risk and an acceptable quality for people who stay in the space with the most economic use of energy. It is more important to reduce pollution than to increase the intensity of ventilation. When designing the quantity of the air the following must be assessed:

- all the pollutants that can influence the health and/or the comfort,

- the strength of the source of a separate pollutant that can appear in the space,

- the maximum concentration of every pollutant that is permissible with regarding to health and comfort.

The quantity of the input air should sufficiently dilute of the pollutants in the air what occupants sense with scent (comfort) and inbreathing (health). Sufficient dilution of pollutants is not always achieved by increasing of the quantity of the ventilation rate:

- a greater quantity does not always mean better air quality. In colder climatic areas a greater quantity of air reduces the relative indoor air humidity which can cause discomfort (dry skin, dry eyes). In moist areas it increases the relative indoor humidity that's reflected in an increase of microorganisms which cause serious problems with air quality. As is shown in Figure 2, large amounts of air do not influence the "sick building" syndrome. A statistically important correlation between the amount of fresh air blown into the offices and the "sick building" syndrome was ascertained in the research [14]: at 10 l/s of the fresh air ventilation rate there were more complaints or "sickness" symptoms than at a smaller quantity of air.

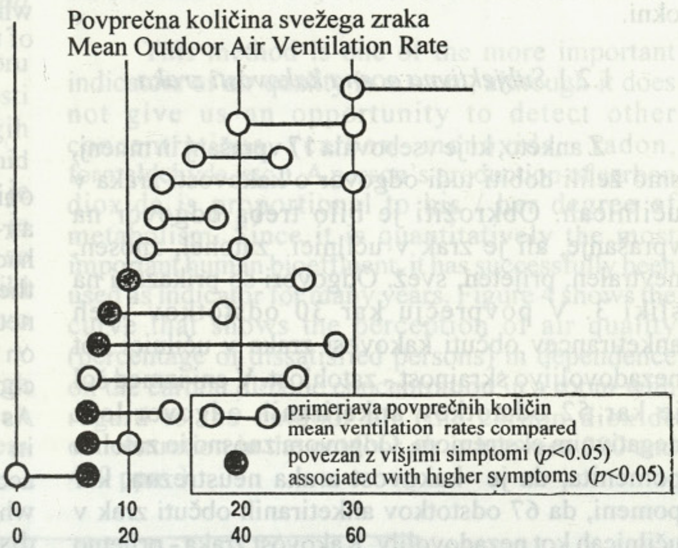
- Večja količina zraka pomeni, ne samo višje stroške za energijo, temveč tudi večjo rabo primarne energije, kar pomeni večjo porabo fosilnih goriv, s tem pa večje onesnaževanje okolja.

- Povečana količina zraka je potrebna zaradi kajenja. Ker kajenje dodatno onesnažuje zrak v prostoru in s tem večjo količino zraka, je potrebno kajenje omejiti (dovoliti le v ločenih prostorih za kajenje). V Sloveniji je kajenje prepovedano v vseh javnih poslopjih od leta 1997.

- A greater quantity of the air means not only greater expenses for energy use and fossil fuels but also greater consumption of primary energy which causes a greater ambient pollution.

- An increased quality of the air is necessary because of smoking. Since smoking additionally pollutes the indoor air, it is necessary to limit smoking (it should be allowed only in the smoking areas). In Slovenia smoking is forbidden in all public buildings since 1997.

STUDIES	OBLIKA ŠTUDIJA	STUDY DESIGN
Jaakkola '91	pregled	cross-sectional
Jaakkola '91	pregled	cross-sectional
Wyon '92	preizkus	experiment
Menzies '93	preizkus	experiment
Wyon '92	preizkus	experiment
Jaakkola '91	pregled	cross-sectional
Jaakkola '91	preizkus	experiment
Nagda '91	preizkus	experiment
Sundell '92	pregled	cross-sectional
Jaakkola '90	preizkus	experiment
Nagda '91	preizkus	experiment
Jaakkola '91	preizkus	experiment
Jaakkola '91	preizkus	experiment
L/s		Liters/s
feet^3/min		Cubic feet/min



Sl. 2. *Simptomi "bolne stavbe" in količina vpihovanega zraka [14].*
Fig. 2. *Sick building syndrome symptons and ventilation rates [14]*

Kakovost notranjega zraka (indikacija je ogljikov dioksid) ne vpliva zgolj na človekovo ugodje in zdravje, temveč tudi na njegovo ustvarjalnost. Raziskava zaposlenih v pisarniških prostorih [8], narejena leta 1994 v Kanadi, je pokazala: 30 % ljudi muči glavobol, 44 % utrujenost in zaspanost, 37 % očesna utrujenost in 69 % ima slabšo delovno učinkovitost. Četrtina obiskov pri zdravniku je povezana s težavami zaradi kakovosti zraka.

Kakovost zraka v prostoru je mogoče izraziti z zahtevami in potrebami ljudi, ki so v prostoru. Ker med njimi obstajajo razlike pri individualnih zahtevah, ki jih ni mogoče popisati, prihajamo do uporabnih rezultatov z anketami. Rezultati statističnih analiz, narejenih v ZDA, v sodelovanju z WHO kažejo, da je v ZDA (pretežno klimatizirani prostori) okoli 20 odstotkov poslopij s kritično kakovostjo zraka, pri 40 odstotkih imajo resne težave. Več ko 50 odstotkov vseh nastalih problemov je posledica neustreznega prezračevanja prostorov.

The indoor air quality (indication - carbon dioxide) does not influence only the people's health and comfort, but also their creativity. The research [8] made in Canada in 1994 among people working in offices showed that 30 % of occupants had headaches, 44 % felt tired and sleepy, 37 % felt eye-tiredness and 69 % had lower working efficiency. About one fourth of consultations with physicicous were connected with poor indoor air quality.

The indoor air quality can be expressed by the demands and needs of people who stay in a space. Since there are differences considering individual demands that can not be listed, we can achieve useful results with the help of questionnaires. The results of a statistical analysis made in the Unites States of America with the cooperation of the World Health Organization show that there are about 20 % of buildings in the USA (mostly with air-conditioning systems) that have critical air quality, and there are 40 % of buildings with serious problems. More than 50 % of problems result from unsuitable ventilation of the buildings.

1.2 Kakovost zraka v šolski stavbi

Številne raziskave zadnjih let po svetu so namenjene ugotavljanju kakovosti zraka. Večina raziskav se je osredotočila na poslovna in šolska poslopja. V letih 1994/95 smo v Sloveniji izvedli raziskavo [9], v kateri smo, poleg možnih ukrepov varčevanja z energijo v šolskih stavbah, analizirali tudi počutje dijakov v učilnicah. Anketirali smo 20 odstotkov dijakov na vsaki izmed analiziranih šol, ki imajo med 400 in 1000 dijakov. Za vse analizirane šolske objekte je značilno, da nimajo umetnega prezračevanja, ogrevanje je izvedeno s standardnim toplovodnim sistemom z nameščenimi ogrevali pod okni.

1.2.1 *Subjektivna ocena kakovosti zraka*

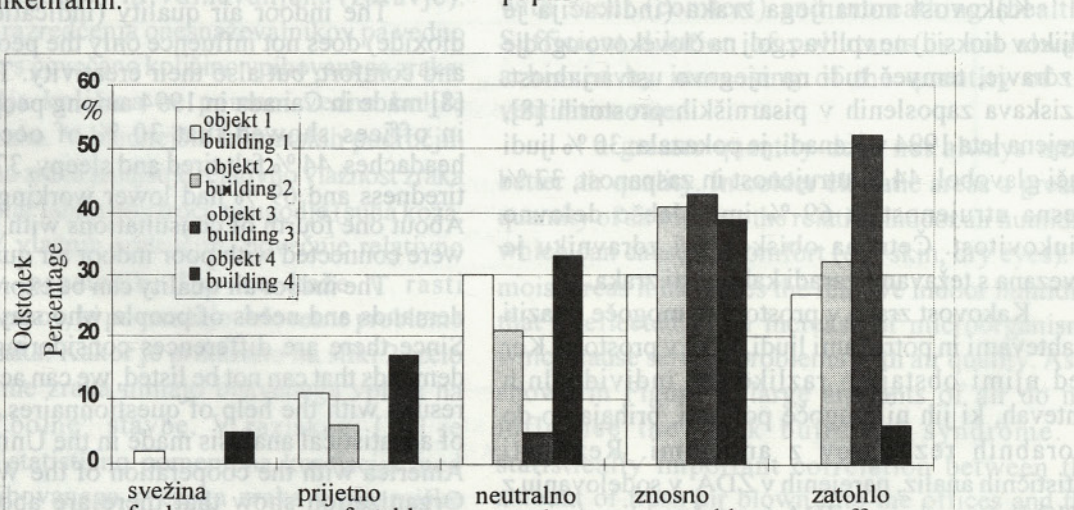
Z anketo, ki je vsebovala 17 vprašanj in mnenj, smo želili dobiti tudi odgovor o kakovosti zraka v učilnicah. Obkrožiti je bilo treba odgovor na vprašanje, ali je zrak v učilnici zatohel, znosen, nevtralen, prijeten, svež. Odgovori so prikazani na sliki 3. V povprečju kar 30 odstotkov vseh anketirancev občuti kakovost zraka v učilnici kot nezadovoljivo skrajnost - zatohlost. V eni izmed šol je kar 52 odstotkov anketiranih odgovorilo z negativnim ekstremom. Odgovora znosno in zatohlo pomenita, da je kakovost zraka neustrezna, kar pomeni, da 67 odstotkov anketiranih občuti zrak v učilnicah kot nezadovoljiv. Kakovost zraka - prijetno in sveže občuti samo 11 odstotkov anketiranih. Na strani zadovoljnih so v povprečju tisti, ki sedijo najbliže oknom, ki se lahko odpirajo. Občuteno kakovost zraka kot nevtralno občuti v povprečju 22 odstotkov anketiranih.

1.2 The air quality in a school

A number of research studies have been published in recent years regarding air quality. Most of them focused on business and school buildings. In the years 1994/95 a research carried on in Slovenia [9], in which, in addition to possible steps of energy saving in school buildings, we also analyzed the feeling of students in the classrooms. A survey of the feeling of pupils was performed in analyzed school buildings with 400 to 1000 pupils. 20 % of pupils of each school were surveyed in different classrooms. It is characteristic of all the studied school buildings that they don't have any ventilation or air-conditioning and the heating is standard water-heating system with radiators placed under the windows. The ventilation was carried out by opening of the windows.

1.2.1 *The questionnaire on air quality*

The survey included 17 questions and opinions, and we wished to get an answer about the air-quality in the classrooms. The surveyed pupils had to encircle the answers to the question of whether the air in the classroom was stuffy, acceptable, neutral, comfortable, fresh. The answers are shown on Figure 3. On average 30 % of all surveyed pupils chose extreme answers: it is stuffy in the classroom. As many as 52 % of answers were extremely negative in one of the schools. The answers stuffy and acceptable are considered as unsuitable air quality, which means that 67 % of those questioned felt dissatisfied with the air in the classrooms. The comfortable and fresh air quality could be felt only by 11 % of pupils who were usually those sitting closest to the windows that could be opened. The neutral quality of the air was felt by 22 % of the pupils.



Sl. 3. *Občutena kakovost zraka - anketa (povprečna standardna deviacija odgovorov 0,67)*

Fig. 3. *The perceived air quality - survey (average standard deviation of answers: 0,67)*

Na vprašanje, z možnostjo odgovora da/ne, ali je v učilnicah dovolj svežega zraka - občutek svežine, je odgovorilo negativno v povprečju 63 odstotkov anketiranih. Odgovori se delno razlikujejo za zimsko (več nezadovoljnih) in prehodno obdobje.

V sklopu vprašanj o kakovosti zraka smo zastavili tudi vprašanje o načinu prezračevanja učilnice. V povprečju je 53 odstotkov anketiranih odgovorilo, da so okna stalno (tudi med poukom, če jih ne moti zunanji hrup) priprta, 42 odstotkov je odgovorilo, da so okna odprta samo med odmori, 5 odstotkov anketiranih pa je odgovorilo, da oken ne odpirajo.

1.2.2 *Meritve koncentracije ogljikovega dioksida*

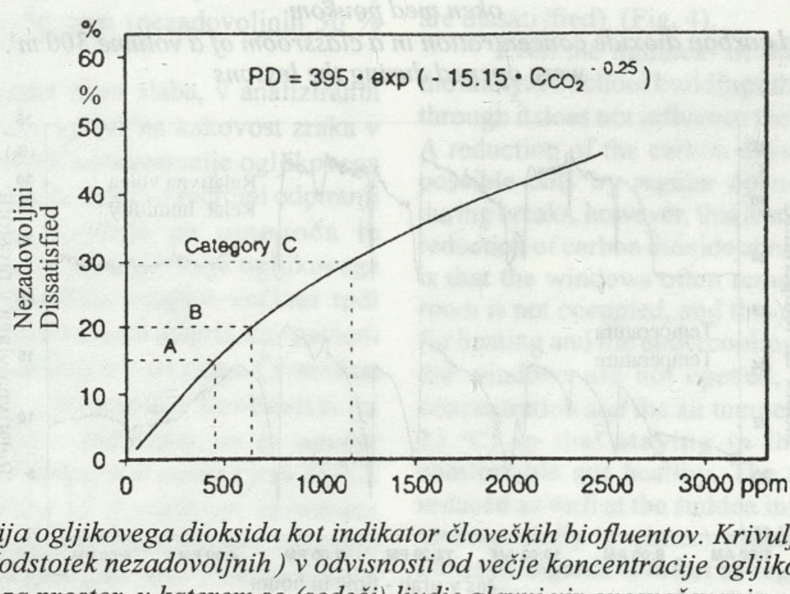
Koncentracija ogljikovega dioksida v prostoru je eden od pomembnejših indikatorjev kakovosti zraka, čeprav s to metodo ne zaznamo drugih koncentracij (ogljikov monoksid, radon, formaldehid itn.). Človekova produkcija ogljikovega dioksida je sorazmerna njegovi stopnji metabolizma. Ker je kolikostno najpomembnejši človeški biofluent, se uspešno uporablja kot indikator že vrsto let. Na sliki 4 je prikazana krivulja, ki prikazuje zaznavo kakovosti zraka (odstotek nezadovoljnih) v odvisnosti od večje koncentracije ogljikovega dioksida v prostoru, glede na zunanji zrak (koncentracija ogljikovega dioksida v zunanjem zraku med 300 in 400 ppm).

On average 63 % of the surveyed pupils gave negative answers to a question as to whether there was enough fresh air in their classrooms (freshness) with a possibility of answering yes / no. The answers differed partially for winter (more of the dissatisfied ones) and transitional (warmer) periods.

On average 53 % of surveyed pupils answered the question of how they ventilated classrooms by saying that they always kept the windows slightly open (during the lessons as well, if they were not disturbed by ambient noise), 42 % answered that the windows were open only during breaks, while 5 % did not open windows at all.

1.2.2 *Measurements of carbon dioxide concentration*

This method is one of the more important indicators of air quality in a room, although it does not give us an opportunity to detect other concentrations (carbon monoxide, radon, formaldehyde, etc.). A person's production of carbon dioxide is proportional to his / her degree of metabolism. Since it is quantitatively the most important human bioeffluent, it has successfully been used as indicator for many years. Figure 4 shows the curve that shows the perception of air quality (percentage of dissatisfied persons) in dependence on the carbon dioxide concentration in a room with regard to the outdoor air (the carbon dioxide concentration in the outdoor air is between 300 and 400 ppm).



Sl. 4. *Koncentracija ogljikovega dioksida kot indikator človeških biofluentov. Krivulja podaja zaznavo kakovosti zraka (odstotek nezadovoljnih) v odvisnosti od večje koncentracije ogljikovega dioksida od zunanje za prostor, v katerem so (sedeči) ljudje glavni vir onesnaževanja zraka [7].*

Fig. 4. *The carbon dioxide concentration as an indicator of human biofluents. The curve shows the perceived air quality (percentage of dissatisfied perssons) as a function of the carbon dioxid concentration higher than outdoors. It applies to spaces where sedentary occupants are exclusive pollution sources [7].*

V šolskih in drugih podobnih prostorih z večjo gostoto ljudi, kjer je človek glavni vir onesnaževanja, se koncentracija ogljikovega dioksida v kratkem času zelo hitro spreminja, kar nam potrjujejo meritve.

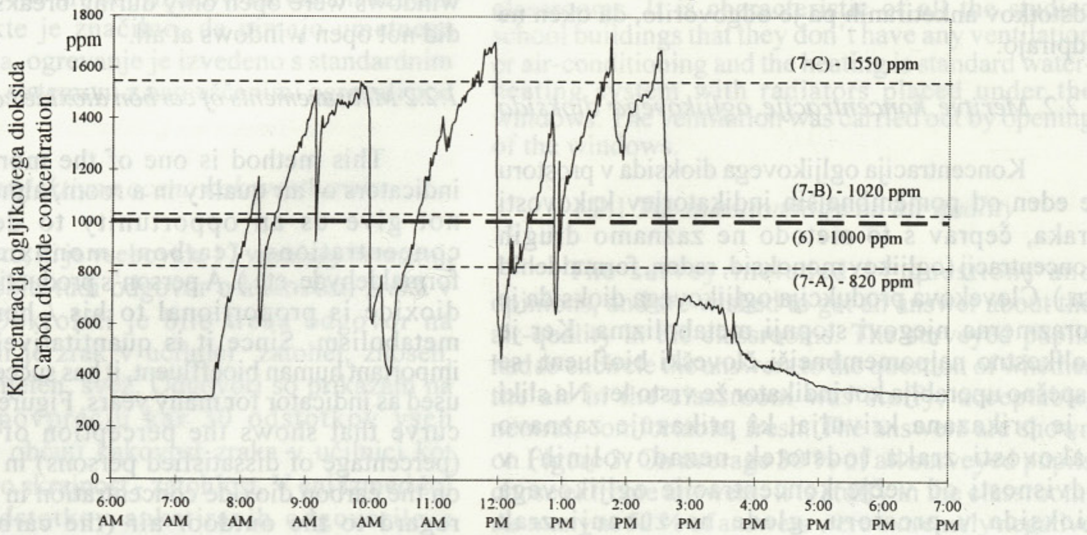
The carbon dioxide concentration can be very quickly changed in school and other similar rooms with a higher density of people. The carbon dioxide concentration was measured in a classroom in winter

Koncentracijo ogljikovega dioksida smo merili v učilnici, v zimskem obdobju (zunanja temperatura med -2 in 4 °C, relativna vlažnost zunanjega zraka med 52 in 78 odstotki).

Meritve so potekale nekaj dni zapored, nepretrgano 24 ur dnevno. V dopoldanskem času pouka je bilo v učilnici med 26 in 31 dijakov. Ker koncentracija ogljikovega dioksida, če ne odpiramo oken v zelo kratkem času v zasedeni učilnici preseže priporočene mejne vrednosti, je bila učilnica v odmorih prezračevana s popolnim odpiranjem oken.

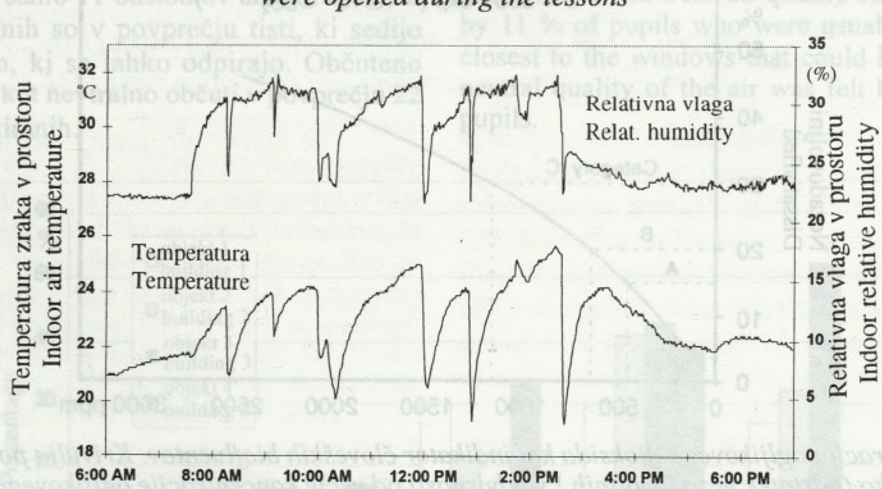
time (the outer temperature being between minus 2 and 4 degrees Celsius, the relative humidity of the outdoors between 52 and 78 %).

The measurements were carried out over successive days, continuously 24 hours per day. There were between 26 to 31 (sitting) people in the classroom in the morning lessons. Since the carbon dioxide concentration exceeds the recommended limited values when a classroom is occupied for a very short time, if the windows are not opened, the classroom was ventilated during the breaks with the windows wide open.



Sl. 5. *Izmerjena koncentracija ogljikovega dioksida v učilnici s prostornino 300 m³, pri odpiranju oken med poukom*

Fig. 5. *The measured carbon dioxide concentration in a classroom of a volume 300 m³, when the windows were opened during the lessons*



Sl. 6. *Izmerjena temperatura zraka in relativna vlažnost zraka v učilnici [13]*

Fig. 6. *The measured air temperature and the relative air humidity in the classroom [13]*

Na sliki 5 je prikazana, z merilnikom izmerjena koncentracija ogljikovega dioksida v učilnici na severni strani stavbe [13], v sredini prostora, v višini glave sedečega dijaka. Hkrati smo na istem mestu merili tudi temperaturo in relativno vlažnost zraka.

Figure 5 shows the carbon dioxide concentration measured in a classroom, located on the north side of the building by a CO_2 meter in the middle of the room and at the height of a sitting pupils [13]. The air temperature and the relative humidity

Med poukom, ko so bila okna zaprta, se je koncentracija ogljikovega dioksida naglo povečevala, ter presegla še dovoljene koncentracije. V času intenzivnega prezračevanja (odmor 5 do 15 minut) se je koncentracija ogljikovega dioksida v učilnici v trenutku zmajšala na vrednost 400 do 600 ppm. Po zapiranju oken in nadaljnji obremenitvi prostora se je ponovno hitro zvečala. Medtem ko so bila okna odprta je prišlo do razgibane izmenjave zračnih mas, kar je povzročilo trenutno znižanje temperature zraka v učilnici za 3 do 9 K, (nihanja se večajo prek dneva), ob hkratnem znižanju že tako majhne relativne vlažnosti zraka v učilnici za 3 do 10 odstotkov (sl.6).

Prezračevanje z odpiranjem oken pomeni le trenutno kakovostnejši zrak v učilnici ob hkratnem neugodnem nihanju temperature in relativne vlažnosti zraka. Prezračevanje prostorov z odpiranjem oken v zimskem času povzroči še dodatno zniževanje relativne vlažnosti zraka v učilnicah.

Največje vrednosti koncentracije ogljikovega dioksida (7 - A, B, C in 6) na sliki 5 so predpisane s standardi. Po standardu [6] je ta meja določena s 1000 ppm. Standard [7] razlikuje 3 stopnje toplotnega okolja ter hkrati tudi tri stopnje kakovosti notranjega zraka. Koncentracija ogljikovega dioksida, za sedečo osebo, sme preseči koncentracije ogljikovega dioksida glede na zunanji zrak pri stopnji "A" do 460 ppm (nezadovoljnih 15 % ljudi v prostoru), stopnji "B" do 660 ppm (nezadovoljnih 20 % ljudi) in stopnji "C" do 1190 ppm (nezadovoljnih 30 % ljudi) (sl. 4).

Čeprav je tesnost oken slaba, v analiziranih šolskih poslopjih nima vpliva na kakovost zraka v učilnicah. Zmanjševanje koncentracije ogljikovega dioksida je edino mogoče doseči z rednimi odpiranji oken med odmori. Slednje pa omogoča le kratkotrajno zmanjšanje koncentracije ogljikovega dioksida. Zaradi tega okna ostajajo večkrat tudi celotni nezasedeni čas odprta ali priprta, kar pomeni izgubo energije ter podhladitev prostora. Če se okna ne odpirajo, poleg (pre)velike koncentracije ogljikovega dioksida v prostorih, se za ugodje neprimerno zviša tudi temperatura zraka (prek 25 °C). Tudi relativna vlažnost se ob velikem, nenadnem vdoru hladnega zunanjega zraka (zlasti pozimi) naglo zmanjša, kar je nesprejemljivo tako z vidika ugodja kakor tudi zdravja.

Prikazani merilni rezultati nazorno potrjujejo rezultate ankete, da sta ugodje in kakovost zraka v prisilno neprezračevanih učilnicah neprimerna. Ljudje v prostoru izražajo dve osnovni zahtevi: prvič tveganje za zdravje zaradi vdihavanja slabega zraka mora biti neznatno in drugič zrak mora biti bolj svež in prijeten, kakor zatohel in dražeč.

were measured at the same time. The carbon dioxide concentration increased rapidly during the lessons when the windows were closed, and exceeded the allowed concentration. The carbon dioxide concentration in the classroom was reduced immediately to its value of 400 to 600 ppm during the period of intensive ventilation (the breaks of 5 to 15 minutes). When the windows were closed again the carbon dioxide concentration increased rapidly. When the windows were open, there was an intensive exchange of air which caused an instant reduction in air temperature in the classroom for 3 to 9 K (the oscillations increase during the day), and a reduction of the already low relative air humidity in the classroom from 3 to 10 % (Fig. 6).

Opening of windows for the ventilation a room also causes an unsuitable oscillation of air temperature and relative indoor air humidity. Using this way of ventilating in the winter time, resulted in an additional reduction of the indoor air humidity.

The limit lines of carbon dioxide concentration (7-A, B, C and 6) on figure 5 are defined by standards. Standard [6] defined the extreme point with 1000 ppm. The prestandard [7] distinguishes 3 levels of air quality where by the carbon dioxide concentration for a person sitting in a room should not exceed the carbon dioxide concentration of the outer air: level "A" 460 ppm (15 % of people in a room are dissatisfied), level "B" 660 ppm (20 % of people are dissatisfied) and level "C" 1190 ppm (30 % of people are dissatisfied). (Fig. 4).

Even the tightness of the windows is bad in the analyzed school buildings the natural ventilation through it does not influence the air quality in rooms. A reduction of the carbon dioxide concentration is possible only by regular opening of the windows during breaks, however, this leads only to a temporary reduction of carbon dioxide concentration. The result is that the windows often remain opened when the room is not occupied, and this means loss of energy for heating and the undercooling of the classroom. If the windows are not opened, the carbon dioxide concentration and the air temperature increase (over 25 °C) so that staying in the room is neither comfortable nor healthy. The relative humidity is reduced as well at the sudden inflow of cold outdoor air (especially in winter) which cannot be accepted either as regards comfort as regards health.

The presented results of measurements confirm clearly the results of the survey which showed that the comfort and the air quality in the classrooms that are not artificially ventilated are unsuitable. The occupants in a space make two requirements of the air in a space. First, the health risk of breathing air should be negligible. Secondly, the air should be perceived fresh and pleasant rather than stale, stuffy and irritating.

2 UČINKOVITOST PREZRAČEVANJA

Koncentracijo ogljikovega dioksida v prostoru lahko zmanjšamo samo z zadostnim (prisilnim) prezračevanjem prostora, ki ga določimo po dveh postopkih:

- Metoda ustrezne količine zraka je najbolj pogosta metoda v praksi. Določa potrebno količino sve ega zraka v m^3/h ali l/s na osebo ali na m^2. Pri tej metodi upoštevamo stopnjo obremenjenosti prostora, pri čemer temeljimo na predpostavki, da bo predpisana količina vpihovanega zraka toliko razredčila koncentracijo onesnaževalnikov v notranjem zraku, da bo njegova kakovost primerna ugodju in neškodljiva za zdravje.

- Metodo ustrezne kakovosti zraka uporabljamo za prostore, v katerih so neobičajni viri onesnaževanja. Metoda predpisuje kakovost zraka v prostoru, ki je določena z nadzorom vseh znanih onesnaževalnikov zraka in dovodom tolikšne količine svežega zraka, da koncentracije ne presežejo kritičnih vrednosti. Poznati moramo (glavne) onesnaževalnike zraka, njihovo jakost in predpisano mejo.

Kakovost zraka je v prezračevanem prostoru lahko različna. Pomembna je predvsem v bivalni coni, v dihalnem območju, kar ocenjujemo z učinkovitostjo prezračevanja (učinkovitost odstranjevanja onesnaženosti). Učinkovitost prezračevanja je odvisna od razporeditve zraka in lokacije virov onesnaževanja v prostoru, temperature zraka in količine svežega zraka. Ima lahko različne vrednosti:

- Če je mešanje zraka in onesnaževalnikov popolno, je učinkovitost prezračevanja enaka vrednosti ena.

- Če je kakovost zraka v coni dihanja boljša kakor v odvedenem zraku, je učinkovitost prezračevanja večja od vrednosti ena. Želeno kakovost zraka v dihalnem območju lahko dosežemo z manjšo intenzivnostjo prezračevanja.

- Če je kakovost zraka v coni dihanja slabša kakor v odvedenem zraku, je učinkovitost prezračevanja manjša od vrednosti ena. Potrebna je večja intenzivnost prezračevanja.

3 POTREBNA KOLIČINA ZRAKA ZA ŠOLSKO POSLOPJE

Izbrano šolsko poslopje ima skupno prostornino 12000 m^3, v kateri je 600 oseb, od tega 580 dijakov. Za prezračevanje dovajamo 28,8 m^3/h (8 l/s) na osebo svežega zraka [6] in [7]. V

2 VENTILATION EFFECTIVENESS

The carbon dioxide concentration in a room can be reduced only with sufficient (artificial) ventilation of the room which can be defined by two procedures:

- the method called "Ventilation Rate Procedure", the method most often used in practice. It defines the required quantity of fresh air in m^3/h or l/s per person or per square meter. The degree of burdening the room is considered with the assumption that its quality of the air blown into the room will thin the concentration of the pollutants in the inner air so that the quality will be comfortable and not harmful for health.

- the method called "Indoor Air Quality Procedure" is used for rooms in which unusual sources of pollution can be found. The method subscribes the indoor air quality. The quality is defined by the control over all the known pollutants and the use of sufficient quantity of fresh air so that the concentration does not exceed the critical values. The (main) agents of air pollution, their strength and the subscribed limit should be known.

The air quality in the room may not be the same throughout a ventilated space. What really counts for the occupants is the air quality in the breathing zone. Such an inhomogeneity of the air quality in a space has an impact on the ventilation requirement. This is expressed by the ventilation effectiveness. The ventilation effectiveness depends on the air distribution and the location of the pollution source in the space. It may, therefore, have different values for different pollutants:

- if there is complete mixing of air and pollutants, the ventilation effectiveness is one,

- if the air quality in the breathing zone is better than in the exhaust air, the ventilation effectiveness is higher than one. The air desired quality in the breathing zone can be achieved with a lower ventilation rate,

- if the air quality in the breathing zone is poorer than in the exhaust air, the ventilation effectiveness is lower than one and more ventilation is required.

3 THE NECESSARY AIR QUANTITY FOR A SCHOOL BUILDING

The chosen school building has a total volume of 12000 m^3. 600 people stay in there, among them there are 580 students. For ventilation is required 28,8 m^3/h prescribed (8 l/s) of fresh air per person učilnice s skupno prostornino 9000 m^3 in površino tal 3000 m^2 vpihujemo 17280 m^3/h (4800 l/s) zraka. Človek povprečno izdiha 5.10^{-6} m^3/s ogljikovega dioksida. Stopnja emisije onesnaženja zraka, ki ga povzroči v učilnici nekadilec, v sedečem položaju (aktivnost < 1, 2 met), ne presega vrednosti 1,5 olf. V telovadnici je 30 dijakov s stopnjo aktivnosti 4 met in emisijo onesnaženja 11 olf. Notranja oprema in pisarniški material onesnažujejo prostor do 0,5 olf/m^2. Latentno onesnaženje zraka izračunamo po modelu, en. (1):

[6] and [7]. 17280 m^3/h (4800 l/s) of air is blown into the classrooms with a total volume of 9000 m^3, and the area of the floor 3000 m^2. A person expires 5.10^{-6} (0,005 l/s) of carbon dioxide on average. The sensory pollution load, that is caused in the classroom by a sitting non-smoker (activity < 1,2 met) does not exceed the value 1,5 olf. In the gymnasium there are 30 students with a degree of activity of 4 met and the pollution load of 11 olf. The inner equipment and the office material pollutes the room to 0,5 olf/m^2. The latent air pollution is calculated by the model (Eq. 1):

$$C = C_e + \frac{G}{\dot{V}_v} \qquad (1),$$

kjer je:

where G means:

$$G = \Sigma\, n_i \cdot g_i \qquad (2).$$

Po modelu (enačba 3) izračunamo odstotek nezadovoljnih ljudi [16]:

The percent of dissatisfied people can be calculated according to the following model (Eq.3) [16]:

$$PD = 395 \cdot e^{-3{,}25 \cdot C^{-0{,}25}} \qquad (3).$$

Glede na vhodne podatke $V = 9000$ m^3, $A = 3000$ m^2, $\dot{V} = 17\,280$ m^3/h, $n = 600$ ljudi, $C_e = 0{,}1$ dec, $n_N = 550$ ljudi, $g_N = 1$ olf, $n_M = 10$ ljudi, $g_M = 5$ olf, $n_H = 30$ ljudi, $n_H = 11$ olf , $n_M = 10$ ljudi, $g_{sl} = 6$ olf, $n_{sl} = 1$ človek, $g_{sl} = 25$ olf, $g_A = 0{,}5$ olf/m^2) znaša odstotek nezadovoljnih ljudi 8,7, oziroma latentno onesnaženje zraka $C = 0{,}62$ decipolov. To pomeni, da dovedena količina zunanjega zraka, ki znaša 28,8 m^3/h (8 l/s) na osebo zadostuje zahtevam za kakovost zraka v šolskih prostorih [7] in [8].

On the basis of the input data ($V = 9000$ m^3, $A = 3000$ m^2, $\dot{V} = 17280$ m3/h, $n = 600$ persons, $C_e = 0{,}1$ dec, $n_N = 550$ persons, $g_N = 1$ olf, $n_M = 10$ persons, $g_M = 5$ olf, $n_H = 30$ persons, $n_H = 11$ olf, $n_M = 10$ persons, $g_{sl} = 6$ olf, $n_{sl} = 1$ person, $g_{sl} = 25$ olf, $g_A = 0{,}5$ olf/m^2) the percentage of dissatisfied occupants is 8,7 % and latent air pollution $C = 0{,}62$ decipols. That means that the inlet quantity of the outdoor air which amounts to 28,8 m^3/h (8 l/s) per person meet the requirements for air quality in schoolrooms.

3.1 Izračun koncentracije ogljikovega dioksida

3.1 The calculation of the carbon dioxide concentration

Koncentracijo ogljikovega dioksida lahko zapišemo kot funkcijo proizvedenega ogljikovega dioksida (metabolizem), dovedene in odvedene količine zraka ter filtriranja in absorpcije zraka. Spremembo koncentracije ogljikovega dioksida v časovnem intervalu dt opisuje diferencialna enačba [10]:

The carbon dioxide concentration can be written as a function of the produced carbon dioxide (metabolism), the inlet and the outlet quantity of air and the filtration and absorption of the air. The following differential equation (Eq. 4) describes the change of the carbon dioxide concentration in the interval dt [10].

$$V \cdot dC(t) = G \cdot dt + C_e \cdot \dot{V}_e \cdot dt - C(t) \cdot \dot{V}_e\, dt - C(t) \cdot \dot{V}_r \cdot E \cdot dt - C(t) \cdot \dot{V}_a \cdot dt \qquad (4),$$

katere rešitev je:

Its solution is:

$$C(t) = C_0 \cdot e^{-\frac{(\dot{V}_e + \dot{V}_a + E.\dot{V}_r).t}{V}} + \frac{C_e \cdot \dot{V}_e + G}{\dot{V}_e + \dot{V}_a + E \cdot \dot{V}_r} \cdot \left(1 - e^{-\frac{(\dot{V}_e + \dot{V}_a + E.\dot{V}_r).t}{V}} \right) \qquad (5).$$

$$C(t) = C_e + (C_o - C_e).e^{-\frac{\dot{V}e.t}{V}} + \frac{G(CO_2).n}{\dot{V}_e}.(1 - e^{-\frac{\dot{V}e.t}{V}}) \quad (6).$$

Povečanje koncentracije ogljikovega dioksida, ki se pojavi v določenem času *t*, izračunamo po en. (6) s poenostavljeno rešitvijo enačbe (5), saj lahko v našem primeru absorpcijo in filtracijo zanemarimo. Koncentracija ogljikovega dioksida v notranjem zraku naj ne presega vrednosti 1000 ppm, kar še zagotavlja udobnost ljudi v prostoru.

The carbon dioxide concentration in the indoor air should not exceed the value of 1000 ppm, and can still assure the comfort of the occupants of the room. The increase of the carbon dioxide concentration which occurs in time t, can be calculated with eq. (6) by a simplification of eq. (5), since the absorption and the filtration can in our case be neglected.

3.1.1 *Povečanje koncentracije v celotni stavbi*

S predpostavko, da znaša koncentracija ogljikovega dioksida v zunanjem zraku 300 ppm in da je začetna koncentracija v notranjem zraku 400 ppm, lahko za čas polne obremenjenosti prostorov šolske stavbe (t = 6 h), in predpisane količine dovedenega zraka, 28,8 m³/h (0,008 m³/s) na osebo, izračunamo iz (6) povečanje koncentracije ogljikovega dioksida (7) (podatki: C_e = 300 ppm, C_0 = 400 ppm, $\dot{V}$ = 17280 m³/h, V = 9000 m³, n = 600 ljudi, $\dot{V}/V$ = 1,92 h⁻¹):

3.1.1 *Increasing of the carbon dioxide concentration in the whole building*

With the assumption that the carbon dioxide concentration in the outdoor air amounts to 300 ppm, and that the initial concentration in the indoor air is 400 ppm, we can calculate the increasing of the carbon dioxide concentration in the air for the time of full occupancy of the school building (t = 6 h) and with the quantity of the inlet air, 28,8 m³/h prescribed (8 l/s). Using the equation 6 we obtain the equation 7 (with: C_e = 300 ppm, C_0 = 400 ppm, $\dot{V}$ = 17280 m³/h, V = 9000 m³, n = 600 persons, $\dot{V}/V$ = 1,92 h⁻¹:

$$C[t] = 300 + (C_o - 300)\cdot e^{-1,92\cdot t} + 1,042\cdot n\cdot\left(1 - e^{-1,92\cdot t}\right) \quad (7).$$

Ker koncentracija ogljikovega dioksida doseže maksimum pri 925 ppm (preglednica 1), torej manjšo vrednost od priporočene, je dovedena količina zraka prevelika.Prezračevalni sistem rabi več energije, kakor je potrebno.

V primeru popolnega mešanja zraka in onesnaževalnikov (ε_v = 1) zadostuje najmanjša potrebna količina dovedenega zraka 25,7 m³/h (0,007 m³/s) na osebo (8):

Since the carbon dioxide concentration reaches its maximum at 925 ppm (Table 1), this value is lover than the recommended one. The outdoor air quantity is little too large and the ventilation system use more energy as it is required.

In the case of complete mixing of the air and pollutants (ε_v = 1) and the minimum required quantity of the inlet air 25,7 m³/h (7,15 l/s) per person (Eq. 8):

$$\dot{V} = \frac{CO_2}{Ci - Ce}\cdot\frac{1}{\varepsilon_v} \quad (8).$$

Pri zmanjšani količini vpihovanega zraka 15444 m³/h in $\dot{V}/V$ = 1,72 h⁻¹ največja dovoljena koncentracija ogljikovega dioksida, izračunana iz (6) po enačbi (9), ne preseže priporočene vrednosti. Sprememba koncentracije ogljikovega dioksida v odvisnosti od časa obremenitve prostora je prikazana v preglednici 2:

At a reduced quantity of the ventilation air 15444 m³/h and $\dot{V}/V$ = 1,72 h⁻¹, the maximum carbon dioxide concentration calculated from equation 6 to equation 9 does not exceed the recommended value. The carbon dioxide concentration changing in the classroom with the time as is shown in the Table 2:

$$C[t] = 300 + (Co - 300)\cdot e^{-1,716\cdot t} + 1,165\cdot n\cdot\left(1 - e^{-1,716\cdot t}\right) \quad (9).$$

Preglednica.1.*Izračunana koncentracija ogljikovega dioksida v notranjem zraku šolske stavbe pri dovodu 28,8 m³/h na osebo vpihovanega svežega zraka*

Table 1. *The calculated course of the carbon dioxide concentration in the indoor air of a school building at 28,8 m³/h of the supply air per person*

čas time h	dovedena količina zraka the inlet air quantity m³/h	število oseb na uro number of persons per hour	količ. zraka na osebo the air quantity per person m³/h	začetna koncentrac. CO_2 v zraku C_o the starting CO_2 concen. C_o ppm	zvišanje konc. CO_2 the increasing CO_2 conc. ppm
7	17280	20	864	400,0	332,4
8	17280	600	28,8	332,4	912,5
9	17280	600	28,8	912,5	925,2
10	17280	600	28,8	925,2	925,2
11	17280	600	28,8	925,2	925,2
12	17280	600	28,8	925,2	925,2
13	17280	600	28,8	925,2	925,2
14	17230	20	864	925,2	320,8

Preglednica. 2. *Izračunania koncentracija ogljikovega dioksida v notranjem zraku šolske stavbe pri dovodu 25,7 m³/h na osebo vpihovanega svežega zraka*

Table 2. *The calculated course of the carbon dioxide concentration in the inner air of a school building with 25,7 m³/h of the supply air per person*

čas time h	količina zraka the inlet air quantity m³/h	število oseb na uro number of persons per hour	količ. zraka na osebo the air quantity per person m³/h	začetna koncentrac. CO_2 v zraku C_o the starting CO_2 concen. C_o ppm	zvišanje konc. CO_2 the increasing CO_2 conc. ppm
7	15444	20	772,2	400,0	373,1
8	15444	600	25,7	373,1	979,8
9	15444	600	25,7	979,8	999,2
10	15444	600	25,7	999,4	999,8
11	15444	600	25,7	999,9	999,8
12	15444	600	25,7	999,9	999,8
13	15444	600	25,7	999,9	999,8
14	15444	20	772,2	999,9	323,5

3.1.2 *Povečanje koncentracije v učilnici*

V učilnici s prostornino 400 m³, je v času od 8. do 14. ure 30 oseb. V prostor dovajamo 28,8 m³/h (8 l/s) zraka na osebo s koncentracijo ogljikovega dioksida 300 ppm. Povečanje koncentracije ogljikovega dioksida v času obremenjenosti učilnice izračunamo po enačbi (10) (podatki: n = 30 ljudi, $\dot{V}$ = 864 m³/h, V = 400 m³:

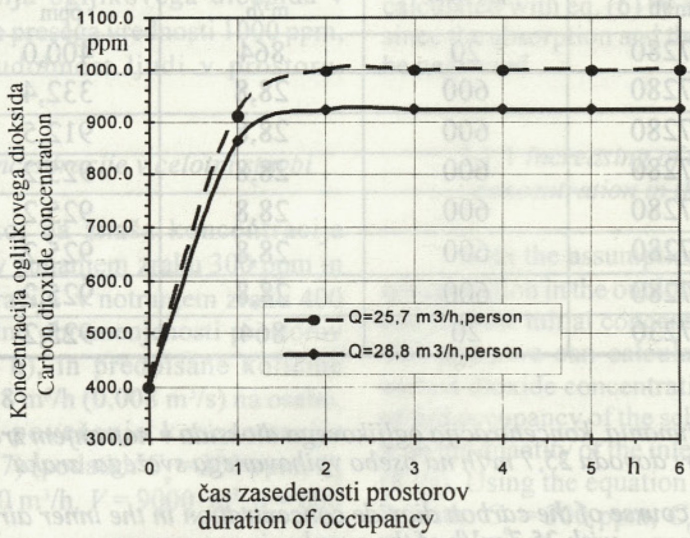
3.1.2 *Increasing of the carbon dioxide concentration in a classroom*

There are 30 people in a classroom with a volume of 400 m³ between 8 a.m. and 2 p.m. We lead in the classroom 28,8 m³/h (8 l/s) of the air with a carbon dioxide concentration of 300 ppm per person. The increase in the carbon dioxide concentration at the time of carbon dioxide loading of the classroom can be calculated from the eq. (10) (data: n = 30 persons, $\dot{V}$ = 864 m³/h, V = 400 m³):

$$C(t) = 300 + (Co - 300)\cdot e^{-2,16\cdot t} + 625\cdot\left(1 - e^{-2,16\cdot t}\right) \qquad (10).$$

Tako, kakor v prejšnjem primeru, je energijsko učinkovitejše, če v učilnico dovajamo minimalno potrebno količino zraka, saj znaša koncentracija ogljikovega dioksida pri vpihu 28,8 m^3/h, "samo" 925 ppm. Zvišanje koncentracije ogljikovega dioksida je razvidno s slike 7 za obe izračunani količini vpihovanega zraka.

It is, as in the former case, energy more efficient, if the minimum needed air quantity is led into the classroom, by blowing 28,8 m^3/h, since the carbon dioxide concentration is "only" 925 ppm. The increase of the carbon dioxide concentration can be seen in Figure 7 for both calculated quantities of the fresh air.



Sl. 7. *Izračunana koncentracija ogljikovega dioksida v odvisnosti od vpihovane količine svežega zraka*

Fig. 7. *Calculated carbon dioxide concentration depending on the fresh air*

3.2 Prihranek energije

V prostor ali poslopje lahko vpihujemo manjšo količino zraka od določene po metodi ustrezne količine zraka, ki zagotavlja zdravju neškodljivo koncentracijo ogljikovega dioksida in ugodje. Zmanjšana količina vpihovanega zraka, glede na predpisano, pomeni prihranek (električne) energije za 10,6 odstotkov [11].

Najnovejši predlog standarda določa količino zraka v odvisnosti od ravni izbranega ugodja, kar neposredno vpliva na rabo energije. Tudi zaradi rabe energije in s tem nastalimi stroški se pripravlja sprememba standarda [7] in [15].

Primer izračunane količine zraka za šolsko stavbo sloni na omejeni koncentraciji ogljikovega diokisida v prostoru 1000 ppm. Raziskave, opravljene v zadnjem času kažejo, da večja koncentracija ogljikovega dioksida v prostoru (do 2500 ppm) nima (neposrednega) vpliva na človekovo zdravje, vpliva pa na ugodje in človekovo storilnost [8] in [15].

3.2. Energy saving

We can blow a smaller air quantity into a space or a building than it is prescribed by the defined method of Ventilation Rate Procedure which assures that the carbon dioxide concentration has no harmful effects on health and comfort. Reducing of the quantity of the fresh air means a saving of the (electrical) energy for 10,6 % [11].

The latest prestandards offers more categories of environmental quality which may be selected in a space to be ventilated. Chosen comfort directly influence to the energy use [7] and [15].

The above case of calculated air quantity for a school building is based on a limited carbon dioxide concentration of 1000 ppm. Research studies performed in recent years show that a higher carbon dioxide concentration (up to 2500 ppm) in a space has no (direct) influence on human health, but it influences the comfort and the creativeness of occupants [8] and [15].

4 SKLEP

Do sedaj kakovosti zraka in prezračevanju prostorov nismo posvečali posebne pozornosti. Cena enega samega dne, ko se človek počuti slabo ali je celo "bolan" zaradi slabega zraka, je najmanj enaka ceni energije, ki je potrebna za občutek svežine zraka v zaprtem prostoru. Pri načrtovanju novih ali sanaciji "bolnih" stavb ne pozabimo upoštevati črke "Z" - zdravje, ki je najmanj tako pomembna kakor do sedaj upoštevani trije "E" - energija, ekologija, ekonomija. Prav skrb za človekovo dobro počutje in zdravje je privedla do izrazitih sprememb razumevanja te problematike.

V poslovnih, stanovanjskih in drugih poslopjih lahko razmeroma poceni ogrevamo tudi s toplim zrakom, kar pomeni, da z enim sistemom zadostimo toplotnemu ugodju in kakovosti zraka. Da v stavbah ne bi imeli več sistemov: toplovodno ogrevanje, prezračevalni sistem in zaradi vse toplejših poletij tudi hladilnega, lahko vse sisteme združimo v enega: klimatizirno napravo, z upoštevanjem vseh možnosti učinkovite rabe energije in kakovosti zraka.

Ali bo sprememba v razumevanju notranjega toplotnega ugodja imela za posledico zamenjavo toplovodnega s toplozračnim ogrevalnim sistemom, bo pokazal čas, predvsem pa gospodarnost.

4 CONCLUSION

Until now, the air quality and the ventilation of spaces has not been given any special attention. The price of only one day when somebody feels bad or even "sick" because of the bad air is at least the same as the price of energy that is necessary to experience the feeling of the fresh air in a closed space. When designing new and sanitizing "sick" buildings, the letter "H" - health, which is at least as important as the three "E" - energy, ecology and economy, should be considered. Care for the comfort and health of people has led to marked change in understanding these problems.

In buildings and dwellings we can use a relatively cheap way of heating with warm air. To avoid having more systems in buildings: water heating, ventilation and air-conditioning for increasingly hotter summers we can combine all of them into one: an air-conditioning device considering all the possibilities of efficient use of energy and high air quality.

It remains to be seen whether or not a change in the understanding of the inner heating comfort will result in the replacement of water-heating system for air-heating systems.

5 SEZNAM OZNAČB

V v m^3	- prostornina prostorov
$\dot{V}$ v m^3/s	- količina dovedenega zunanjega zraka,
g v olf	- intenzivnost virov onesnaženja zraka,
C v dec	- latentno onesnaženje zraka v prostoru,
C v ppm	- koncentracija ogljikovega dioksida
PD	- odstotek nezadovoljnih ljudi
n	- število oseb,
t v h	- čas,
ε_v	- učinkovitost prezračevanja.

Indeksi

e	- zunaj
i	- znotraj
o	- začetno stanje
H	- visoko
M	- srednje
L	- nizko
S	- kadilec

5 NOMENCLATURE

V in m^3	- room volume
$\dot{V}$ in m^3/s	- quantity of inlet air
g in olf	- pollution source intensity
C in dec	- latent air pollution
C in ppm	- concentration
PD	- percentage of dissatisfactory people
n	- number of persons
t in h	- time
ε_v	- ventilation effectiveness

Index

e	- outdoor
i	- indoor
o	- starting
H	- high
M	- middle
L	- low
S	- smoker

6 LITERATURA
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