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Kakovost zraka v poslopjih — Vzroki za nastale težave in njihovo odpravljanje

Indoor Air Quality - Problem Identification and Elimination

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Naftna kriza, ki se je pojavila v sedemdesetih letih in z njo povezan velik skok cene goriv, je botrovala nekakšni krizni miselnosti, da je treba za vsako ceno varčevati z energijo, ne glede na posledice, ki jih lahko takšno početje prinese. Nekaj let pozneje, ko so bile zelo zmanjšane minimalno predpisane količine svežega zraka za prezračevanje prostorov, se je prvič pojavil pojem bolnih poslopij, v katerih so se ljudem začela pojavljati različna bolezenska znamenja. Kakovost zraka v prostoru (IAQ) je postalo pomembno vprašanje, ki mu bo v prihodnosti posvečena velika pozornost. Razvoj znanja in razumevanje te problematike bodo v prihodnosti omogočali in hkrati od projektantov in inženirjev zahtevali oblikovanje takšnih poslopij, ki bodo ljudem zagotavljala bolj zdravo bivalno okolje.

The oil embargo of the 1970s and increased energy prices created a crisis mentality, that is, a belief that fast action had to be taken to conserve energy regardless of the consequences. A few years later when the ventilation rates for buildings were drastically reduced the term sick buildings appeared for the first time. This term has been used to describe indoor environmental conditions that have given rise to constellation of occupant reported subjective symptoms. Indoor air quality (IAQ) is an issue that will continue to gain prominence in the future. Advances in scientific knowledge and understanding about the indoor air quality will enable and require building designers and engineers to design buildings so as to provide the occupant with healthier indoor conditions.

0 UVOD

V zadnjih dvajsetih letih je veda o prezračevanju poslopij zelo napredovala. V prvem delu tega obdobja je bila pozornost inženirjev usmerjena predvsem na razumevanje mehanizmov vdora zraka v poslopja, z namenom, da bi nadzirali in pogosto zmanjševali naključni vdor svežega zraka v poslopja. Naftna kriza, ki se je pojavila v sedemdesetih letih in z njo povezan velik skok cene goriv, je botrovala nekakšni »krizni miselnosti«, da je treba za vsako ceno varčevati energijo, ne glede na posledice, ki jih takšno početje lahko prinese. Rezultat tega obdobja so bili objekti, pri katerih je bila tesnost povečana na maksimum. Prav tako pa je bil uveden tudi nadzor prezračevanja.

Ob zmanjšanem pritoku svežega zraka se je v poslopjih pojavil problem slabe kakovosti zraka v prostorih. Zaradi mednarodno uveljavljene kratice za kakovost zraka v prostoru IAQ (Indoor Air Quality), jo bomo v nadaljevanju uporabljali tudi v našem prispevku. V tem času se je prvič pojavil pojem bolnih poslopij. To so objekti, v katerih se ljudem, ki v njih živijo ali delajo, začno pojavljati različni bolezenski simptomi, ki jih je klinično težko diagnosticirati. Simptomi, ki se običajno pojavljajo, so: glavobol, omotičnost, oteženo dihanje,

0 INTRODUCTION

In the last twenty years ventilation philosophy has experienced major changes. In the first part of this period, considerable efforts among engineers were made to understand the mechanism of air infiltration in buildings in order to control, and often to reduce, the accidental ventilation. The oil embargo of the 1970s and increased energy prices created a »crisis mentality«, that is, a belief that fast action had to be taken to conserve energy regardless of the consequences. The result was tight buildings with the minimum possible infiltration. Ventilation rates were decreased to a minimum. Also the ventilation control has been introduced.

Along with the decrease in ventilation rates many buildings experienced the problem of poor indoor air quality. Since the abbreviation IAQ which stands for the Indoor Air Quality is now accepted worldwide, it will be used in the remainder of this paper. In that time the term sick buildings syndrome appeared for the first time. This term has been used to describe indoor environmental conditions that have given rise to a constellation of occupant-reported subjective symptoms that are clinically hard to diagnose or confirm. The usual symptoms are headache, dizziness, shortness of breath, a stuffy feeling, congested or irritated upper respiratory tract,

zadušljiv občutek, vzdraženje zgornjih dihalnih poti, zaspanost, pekoče oči itn. So odziv organizma na akutno neugodje in so razmeroma hitro minljivi, po tem, ko človek zapusti takšen prostor. Intenzivna in dolgotrajna izpostavljenost neprimernemu zraku v poslopju lahko privede do kroničnih bolezenskih znakov, to so zvišana telesna temperatura, infekcije, vnetja in podobno. To je bil začetek drugega dela omenjenega obdobja, v katerem se je težišče raziskav preneslo na probleme razumevanja vzrokov za nastanek bolnih poslopij. Splošno mnenje strokovnjakov se je, kljub tedanji ceni energije, nagnilo na stran povečevanja količine svežega zraka za zagotavljanje zdravega okolja in ugodja v poslopjih.

Spremembe v razumevanju te problematike so se kmalu pokazale kot spremembe nacionalnih standardov in normativov za področje ventilacije in ugodja v poslopjih. Do takrat skromno predpisane minimalne potrebne količine svežega zraka so narasle, za nekatere primere celo nad vrednosti iz časov pred energetsko krizo.

V dvajsetih letih tega stoletja, ko so se pojavljale prve naprave za klimatiziranje prostorov, so jih prodajali kot naprave, ki bodo človekovo okolje naredile predvsem zdravo. Dandanes pa krivimo prav te naprave za vrsto zdravstvenih težav. Žal je naraven odziv ljudi, da pri težko rešljivih problemih radi krivimo nekoga drugega. To je še posebej značilno za probleme IAQ. Najemniki prostorov krivijo lastnike objekta, lastniki objektov krivijo arhitekte, arhitekti inženirje itn. Tako seveda ne pridemo daleč, ugotavljamo lahko le, da se moramo reševajanja problemov IAQ lotiti multidisciplinarno.

Rezultati statističnih analiz, ki sta jih izvedli ameriška organizacija U.S. Environmental Protection Agency (EPA) in Svetovna zdravstvena organizacija (WHO) kažejo, da je v ZDA približno 20 odstotkov poslopij s kritičnim IAQ, 40 odstotkov ima resne težave, preostalih 40 odstotkov poslopij pa jih nima [1]. Iz ugotovitev, ki jih je objavila ameriška organizacija National Institute for Occupational Safety and Health (NIOSH) je mogoče razbrati, da je več ko 50 odstotkov vseh problemov IAQ povezanih z nezadostnim oziroma neprimernim prezračevanjem poslopij.

1 PREGLED ŠKODLJIVIH SNOVI V ZRAKU IN NJIHOVI VPLIVI NA ČLOVEKOVO ZDRAVJE

Med dejavniki, od katerih je odvisno splošno človekovo ugodje v prostoru, sta med najpomembnejšimi toplota in čist zrak. Poleg teh se običajno omenja še ustrezna razsvetljenost prostora, primerna raven hrupa, notranja ureditev itn. Toplotno ugodje človeka je razmeroma dobro raziskano in njegovo vrednotenje ne dela posebnih težav.

drowsiness, burning eyes etc. These symptoms are generally related to responses of acute discomfort and are rapidly reversible. Long-term exposure to poor indoor air quality conditions may cause pathological illness (building related illness) associated with high fever, infection of tissue, inflammation etc. At the beginning of the second part of the above mentioned period concerted efforts were made to understand the causes of sick buildings. Despite the energy prices in those days the experts general opinion has changed towards increased ventilation rates in order to meet health and comfort requirements.

The understanding of these problems influenced the changes in national ventilation and comfort standards. The previously reduced ventilation rates increased drastically, in some cases even beyond those recommended before the energy crisis.

In the 1920s, when the air-conditioning industry was in its infancy, air conditioning was touted as a way of making people healthy. Today it is not unusual to hear people blame air conditioning for making them sick. Unfortunately, the natural reaction when there is a problem - particularly one for which there is no easy solution - is to try to blame someone else. This behaviour seems to be especially common in the case of IAQ problems. Tenants blame building owners, owners blame architects, architects blame engineers etc. This is not the right way to do it but we may recognize from this the need to employ a multidisciplinary approach to the evaluation of IAQ problems, an approach that views a building as a complex, dynamic system.

The results based on statistics conducted by the Environmental Protection Agency (EPA) and World Health Organization (WHO) indicate that approximately 20% of U.S. buildings have serious IAQ problems, 40% somewhat serious problems, and another 40% have no serious problems [1]. A National Institute for Occupational Safety and Health (NIOSH) study concluded that over 50% of IAQ problems reported were related to poor or inadequate ventilation of buildings.

1 THE REVIEW OF AIR POLLUTANTS AND THEIR HEALTH EFFECTS

Among the different factors that influence the overall occupants comfort, thermal comfort and indoor air quality are the most important. Appropriate workplace illumination, acceptable noise level and ergonomics are also frequently mentioned but these topics will not be covered in this paper. Thermal comfort is quite well understood today and its evaluation rather predictable.

Kakovost zraka v prostoru je odvisna od mnogih parametrov:

— kakovosti zunanjega zraka,

— oblike in ureditve prostorov v objektu,

— vrste prezračevalnega ali klimatizacijskega sistema,

— načina delovanja tega sistema in njegovega vzdrževanja,

— virov onesnaženja zraka v prostorih in njihove moči.

Kakovost zraka v prostorih stanovanjskih objektov, poslovnih prostorov in drugih neindustrijskih poslopij, je problem, ki mu strokovnjaki, zaradi številnih pritožb in manjše delovne storilnosti, posvečajo vedno večjo pozornost. Resnica je, da je izpostavljenost onesnaženemu zraku v objektih lahko prav tako škodljiva zdravju kakor izpostavljenost onesnaženemu zunanjemu zraku. Raziskave kažejo, da velik del ljudi preživi tudi do 90 odstotkov časa v zaprtih prostorih objektov in transportnih sredstev.

Analize kažejo, da so pritožbe ljudi zaradi slabe kakovosti zraka pogostejše v umetno prezračevanih poslopjih, kakor pa v naravno prezračevanih stavbah. Strokovnjaki verjamejo, da so vzroki za pritožbe predvsem v škodljivih snoveh, znotraj samih prostorov (gradbeni materiali, notranja oprema, naprave, sam prezračevalni sistem), ne pa toliko zaradi škodljivih snovi, ki jih oddajajo ljudje v poslopjih. Ker so bolj problematične umetno prezračevane stavbe, lahko sklepamo, da so nepravilno načrtovani in nekorektno vzdrževani klimatizacijski sistemi pogost vzrok za slabo kakovost zraka.

V nadaljevanju bomo prikazali nekaj najpomembnejših škodljivih snovi, s katerimi se srečujemo pri reševanju problemov IAQ [2], [3].

Ogljikov dioksid — CO_2

To je plin brez barve in vonja, nastaja pri zgorevanju snovi, ki vsebujejo ogljik. Viri CO_2 v objektih so zgorevanje v kurilnih napravah in metabolizem pri ljudeh. V poslovnih objektih, pisarnah, šolah itn., kjer se zadržuje večje število ljudi, je CO_2 razmeroma dober pokazatelj slabega zraka, ni pa edini. Izpostavljenost večjim koncentracijam CO_2 povzroča glavobol, zaspanost in vrtoglavico (> 5.000 ppm oziroma > 0,5 odstotkov). V primerjavi z nekaterimi drugimi škodljivimi snovmi CO_2 ne moremo filtrirati, absorbirati ali adsorbirati. Njegovo koncentracijo lahko zmanjšamo samo z zadostnim prezračevanjem prostora.

There are many factors that influence indoor air quality:

— the quality of outside air,

— building and interior design,

— Heating, Ventilation and Air Conditionning System (HVAV) system design,

— HVAC system operation and maintenance,

— number and intensity of indoor contaminant sources.

Many recent complaints about IAQ from occupants and reported decrease in workers' ability to work in residential, commercial and other non-industrial environments have made IAQ an issue of prominence for a wide range of professions. The fact is that exposure to poor indoor air quality can be as harmful as exposure to polluted outside air. It was shown that a huge portion of human population spends up to 90% of its time indoors.

Studies in naturally and mechanically ventilated buildings have shown that more complaints related to building sickness were found among occupants of the mechanically ventilated buildings. The experts believe that these complaints are caused more by pollutants emitted internally by building materials, furnishing, equipment and ventilation systems than by the occupants of the building themselves. Indeed, the poorer indoor air quality in the case of mechanically ventilated buildings seems to support the argument that poorly designed and maintained ventilation plants are major contributors to poor indoor air quality.

In this section some more important pollutants encountered in solving IAQ problems will be presented [2], [3]:

Carbon dioxide — CO_2

An odourless, colourless gas that is formed whenever carbon-containing substances are burned. Its sources in indoor air include combustion in appliances and normal metabolic activity of building occupants. In office buildings, schools and similar buildings occupied by multitudes CO_2 can be a good index of poor indoor air quality, but not the only one. Exposure to high levels of carbon dioxide is associated with complaints of headache, drowsiness and dizziness (>5.000 ppm i.e. > 0.5%). Unlike some other contaminants CO_2 can not be filtered, absorbed or adsorbed. High levels of CO_2 can only be lowered by increased ventilation rates.

Ogljikov monoksid — CO

To je brezbarvni plin, ki nastaja pri nepopolnem zgorevanju ogljikovodikov, goriv, lesa ali cigaret. V krvi se veže na hemoglobin in s tem zmanjšuje zmožnost krvi za prenos kisika po človeškem organizmu. To otežuje dihanje in povzroča glavobol, slabost v želodcu, pri visokih koncentracijah tudi nezavest in smrt.

Dušikovi oksidi — NO_x

Dušikovi oksidi nastajajo pri gorenju goriv pri zvišani temperaturi. Količina dušikovih oksidov je sorazmerna temperaturi zgorevanja in času zadrževanja N_2 v vročih plinih. Najbolj je problematičen dušikov dioksid. Akutna izpostavljenost zvišani koncentraciji NO_2 povzroči zmanjšano prehodnost dihalnih poti in infekcije respiratornih organov.

Formaldehid — HCHO

To je kemijska spojina, ki se veliko uporablja v industriji izolacijskih materialov (urea-formaldehidna pena) kot vezivo pri izdelavi vezanih lesnih plošč (pohištvo), pri proizvodnji kozmetičnih preparatov, v tekstilni in papirni industriji. Formaldehid prodre v človekovo telo prek dihalnih organov, s hranjenjem in z adsorpcijo v koži. Draži nosno in očesno sluznico, povzroča pekoče grlo, glavobol, rahlo omotičnost in vnetje zgornjih dihalnih organov. Je genotoksičen, raziskave pa kažejo tudi na možnost karcinogenega delovanja.

Vonjave

Vonjave so povezane z navzočnostjo in aktivnostjo ljudi, kuhanjem, sanitarnimi dejavnostmi, odpadki itn. Pogosteje so omenjane z občutkom neugodja, kakor pa z resnejšimi zdravstvenimi posledicami. Človeški nos je izredno občutljiv za vonjave, saj zazna že koncentracije nekaj ppb (10^{-9}). P.O. Fanger je leta 1988 predstavil dve, do takrat neznani fizikalni enoti: olf in decipol, ki sta neposredno povezani s kakovostjo zraka v prostoru in omogočata meritve različnih onesnaževalnikov zraka na enotni lestvici [4]. Jakosti virov vonjav je vrednotil v primerjavi z dobro znanim virom — standardno sedečo osebo, ki je v toplotnem ravnotežju s prostorom. Enota olf določa stopnjo emisije onesnaževalnikov zraka, ki jih oddaja ena oseba. Enota decipol je definirana kot občutena moč onesnaženosti zraka, ki jo povzroči oseba v prostoru, prezračevanim z 10 litrov/s svežega zraka. Odstotek nezadovoljnih ljudi v prostoru kot funkcija dovedenega prostorninskega toka svežega zraka v prostor, v katerem je standardna oseba (1 olf), je prikazan na sliki 1.

Redčenje vonjav se običajno doseže z dovajanjem zadostne količine svežega zraka v prostor.

Carbon monoxide — CO

An colourless gas that is associated with incomplete combustion of all types of fuels, wood or cigarettes. Carbon monoxide combines with haemoglobine resulting in a decrease of the oxygen carrying capacity of human blood. This results in complaints of shortness of breath, headache, nausea, and, at high levels, coma and death.

Nitrogen oxides — NO_x

Combustion of fuel sources at elevated temperatures generates oxides of nitrogen. Concentrations generated increase with higher temperature and N_2 time-lag in hot combustion gases. Nitrogen dioxide is a major health concern. Acute exposure to high concentrations of NO_2 results in increased respiratory passage resistance and respiratory infections.

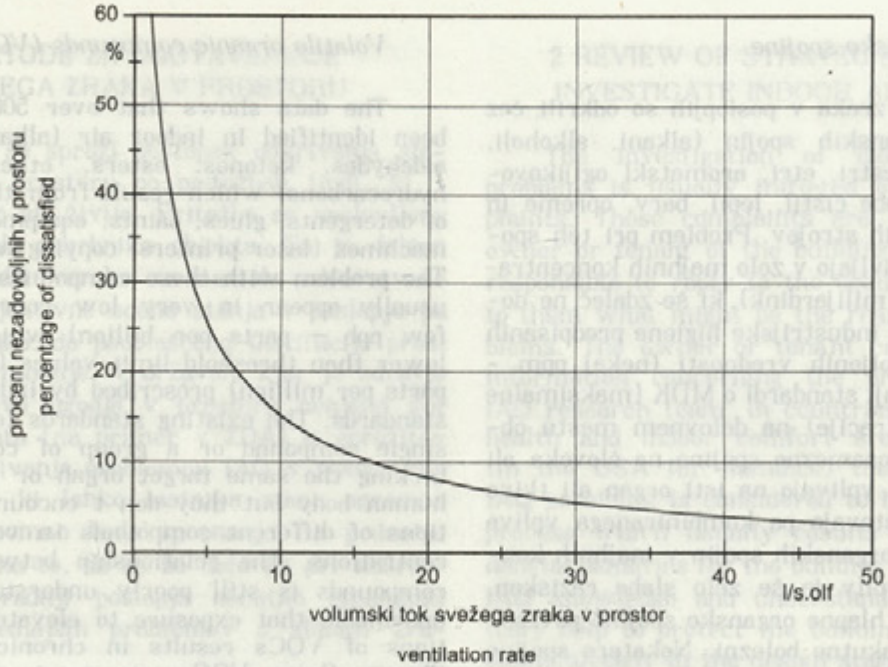
Formaldehyde — HCHO

A chemical that is extensively used in insulation material production (urea-formaldehyde foam), as an adhesive in compressed wood products, in cosmetics, textiles and paper industry. Formaldehyde can enter the body through inhalation, ingestion or skin adsorption. It is irritating to the eyes and nose, causes coughing, headache, slight dizziness and infections of upper respiratory tract. It is genotoxic and a potent carcinogen for humans.

Odours

Odours are associated with occupancy, cooking, bathroom activities, waste etc. Odour pollution is more often associated with discomfort rather than serious health effects. The human sense of smell permits perception of very low concentrations of odours (a few ppb). P.O. Fanger introduced in 1988 two new physical units, namely olf and decipol, the air quality units which enable the evaluation of different pollutants on the same scale [4]. He quantified air pollution sources by comparing them with a well-known source - a standard sedentary person in thermal comfort. One olf is defined as the emission rate of air pollutants from a standard person. The decipol unit is defined as the perceived intensity of air pollution caused by one standard person located in the room which is ventilated by 10 litres/s of fresh air. Percentage of dissatisfied as a function of ventilation rate for the enclosure with one standard person (1 olf) is shown in Figure 1.

The best way to eliminate odours from a room is to provide the room with the appropriate



Sl. 1. *Odstotek nezadovoljnih kot funkcija dovedene količine svežega zraka na en olf [4].*
Fig. 1. *Percentage of dissatisfied as a function of ventilation rate for one olf [4].*

Najuspešnejša metoda odstranjevanja vonjav pa je filtriranje zraka skozi filter iz aktivnega oglja. Aktivno oglje po načelu adsorpcije iz zraka odstranjuje pline, pare in vonjave (telesne, smog, cigaretni dim, iz toaletnih prostorov, čistil, kozmetike, deodorantov, detergentov, hrane, barv, lepil, parfumov, izrabljenega in zatohlega zraka).

Lebdeči trdni delci

Zelo pogosto je njihova koncentracija znotraj objektov večja kakor zunaj. V obliki prahu, dima in aerosolov kemično in mehansko dražijo sluznice nosu, oči in žrela in slabšajo funkcije zgornjih dihalnih poti. Lokalno jih lahko odstranjujemo z učinkovitimi filtri HEPA ali elektrostatičnimi filtri.

Cigaretni dim

Produkti zgorevanja tobaka vsebujejo zmes trdnih delcev, plinov in hlapnih organskih spojin, ki škodujejo zdravju in izrazito povečujejo neugodje ljudi in smrad v prostoru. Vpliv na človekovo zdravje je dobro raziskan. Daljša izpostavljenost povzroča vzdraženje očesne in nosne sluznice, glavobol in vnetje grla. Katran in nikotin v cigaretnem dimu sta karcinogeni snovi in imata lahko usodne posledice za človekovo zdravje. Najboljši način zmanjševanja koncentracije cigaretnega dima v objektu je prepoved kajenja, nato lokalno odsesovanje zraka iz onesnaženega prostora. Odpadni zrak vodimo zunaj poslopja, daleč od zajemov svežega zraka.

ventilation rate. Air filtration through an activated carbon filter is also the process of choice for odour-polluted indoor air. Activated carbon effectively adsorbs the gases, vapours and odours from body, smog, cigarettes, toilets, detergents, food, paints, glues, perfumes and stuffiness.

Respirable suspended particles (RSP)

It is quite common for indoor concentrations of particulate matter to exceed outdoor levels. In forms of dust, fumes or aerosols they chemically and mechanically irritate at the deposition sites within the respiratory tract and impair respiratory function. Locally they can be eliminated from the air using high efficiency particulate (HEPA) or electrostatic filters.

Environmental tobacco smoke (ETS)

ETS contains a complex mixture of respirable particles, combustion gases and chemicals which threaten human health, cause general discomfort and an undesirable odour. These effects are well understood today. Acute exposure to elevated concentrations can result in ocular and upper respiratory irritation, headache and throat inflammation. Tar and nicotine are carcinogens and can have fatal health effects on people exposed. The most effective way to eliminate the ETS from the air is a non-smoking policy within the building and the second most effective is a local exhaust ventilation. The exhausted air is directly extracted out of the building, at locations far away from the fresh air intakes.

Hlapne organske spojine

Pri analizah zraka v poslopjih so odkrili čez 500 hlapnih organskih spojin (alkani, alkoholi, aldehidi, ketoni, estri, etri, aromatski ogljikovodiki) zaradi uporabe čistil, lepil, barv, opreme in delovanja nekaterih strojev. Problem pri teh spojinah je, da se pojavljajo v zelo majhnih koncentracijah (nekaj ppb - milijardink), ki še zdaleč ne dosegajo s standardi industrijske higiene predpisanih maksimalnih dovoljenih vrednosti (nekaj ppm - milijonink). Sedanji standardi o MDK (maksimalne dovoljene koncentracije) na delovnem mestu obravnavajo vpliv posamezne spojine na človeka ali skupine spojin, ki vplivajo na isti organ ali tkivo v telesu, ne upoštevajo pa kombiniranega vpliva različnih hlapnih organskih spojin v majhnih koncentracijah. Ta vpliv je še zelo slabo raziskan, nesporno pa je, da hlapne organske spojine povzročajo kronične in akutne bolezni. Nekatere spojine so karcinogene. Onesnaženost zraka z organskimi spojinami je mogoče zmanjšati z razpoznavanjem in odstranjevanjem virov ter pogostejšim prezračevanjem poslopij.

Radon

Je radioaktivni plin brez vonja in okusa. Pojavlja se v naravi pri razpadu radija, ta pa nastaja z razpadom urana. Ker sta radij in uran v majhnih količinah sestavini skalnate in zemeljske strukture tal, radon v večjih ali manjših količinah nahajamo povsod. Radon kot plin zlahka prehaja skozi majhne razpoke v tleh proti površini, od tam pa skozi odprtine (okna, razpoke, kletni prostori) zaide v stavbe. Količina radona v stavbi je sorazmerna koncentraciji v tleh pod stavbo, poroznosti tal in podtlaku v stavbi, ki je lahko naravna razlika tlakov zaradi razlike temperatur ali umetnega prezračevanja. Običajno v objektih zaznamo povečano koncentracijo radona 222, katerega razpolovna doba je približno štiri dni. Radon v objektu razpada in oddaja delce alfa, ki se vsedajo na lebdeče respirabilne prašne delce v zraku in lahko poškodujejo pljučno tkivo. Radon v stavbah je vzrok za veliko hudih pljučnih obolenj. Koncentracijo radona v stavbi lahko nadziramo s preprečevanjem njegovega vstopa v notranjost in z odstranjevanjem radona, ki je že zašel v poslopje. V Sloveniji npr. smo imeli velike probleme z radonom v otroškem vrtcu v Idriji.

Poleg naštetih onesnaževalnikov zraka so pomembni še: lebdeči delci azbesta, lebdeča vlakna mineralnih in kamenih voln, plesni, mikroorganizmi (bakterije), ozon itn., katerih vpliv na človekovo zdravje je različno dobro raziskan.

Volatile organic compounds (VOC)

The data shows that over 500 VOCs have been identified in indoor air (alkanes, alcohols, aldehydes, ketones, esters, ethers, aromatic hydrocarbons) which result from the indoor use of detergents, glues, paints, equipment, operating machines (laser printers, copying machines) etc. The problem with these compounds is that they usually appear in very low concentrations (a few ppb — parts per billion) which are much lower than threshold limit values (a few ppm — parts per million) prescribed by industry hygiene standards. The existing standards focus on every single compound or a group of compounds attacking the same target organ or tissue in the human body but they don't encounter combinations of different compounds in very low concentrations. The relationship between different compounds is still poorly understood but it is undeniable that exposure to elevated concentrations of VOCs results in chronical and acute illness. Some VOCs are carcinogens. Control of VOC contamination of indoor air is accomplished by a combination of identification and removal of sources and increased ventilation.

Radon

Radon is an odourless and tasteless radioactive gas. It occurs naturally, a product of the radioactive decay of radium, which is formed from the decay of uranium. Since radium and uranium are ubiquitous elements in rock and soil, radon is also. As a gas it can move easily through very small spaces of soil and rock and then enters residences through cracks and openings (windows, joints, cellar openings). The amount of radon entering the residence is dependent on the concentration of radon in the surrounding soil and rock, the soil porosity and lower air pressure in the residence which may be caused by a stack effect or operation of exhaust fans. The isotope of radon most commonly of concern indoors is radon-222 which has a half-life of approximately 4 days. Once in the building, radon decays and emits alpha particles which attach themselves to respirable suspended particles. If inhaled, these particles may damage lung tissue. The elevated concentrations of radon result in many serious lung diseases. Two approaches in reducing exposure to indoor radon are to prevent radon entry into a residence and to remove radon or radon decay products after entry into a residency. One of the major Slovenian cases of indoor radon was in nursery-school in Idrija.

Besides these indoor air pollutants the following are also important: respirable asbestos fibres, man-made mineral fibres, mould, microbes, ozone, etc. whose principles of the way they affect human health have reached different levels of understanding.

2 METODE ZA UGOTAVLJANJE SLABEGA ZRAKA V PROSTORU

Običajno se sproži postopek odkrivanja slabega zraka v prostoru po pritožbah ljudi, ki v poslopju delajo ali živijo. Pritožbe so naslovljene na lastnika ali oskrbnika objekta. Ta je dolžan ljudem pojasniti vzroke za nastale zdravstvene težave, do objektivne ocene stanja v poslopju pa lahko pride tako, da pooblaščeno institucijo prosi za strokovno mnenje. V državah, kjer je zdravje ljudi in njihovo ugodje v prostoru cenjeno kot visoka vrednota (na primer v ZDA), je sprožitev postopka odkrivanja problemov IAQ v stavbi sila resen proces, ki lahko lastnika stane ogromno denarja. Nedvomno bodo spoznanja na področju IAQ vplivala na to, da se bo dalo že pri načrtovanju in izgradnji poslopja občutno zmanjšati verjetnost kasnejših problemov s slabim zrakom.

Raziskava zraka v prostorih terja izrazito večstransko sodelovanje. Navadno so k takšni raziskavi povabljeni naslednji strokovnjaki [6]:

— gradbeniki, arhitekti (gradbeno-arhitektonske značilnosti objekta),

— strojniki (prezračevalni in klimatizacijski sistemi),

— zdravniki (zdravje in ugodje ljudi),

— strokovnjaki za industrijsko higieno (objektivno stanje zraka v poslopju),

— sociologi (človekovo subjektivno zaznavanje razmer v stavbi).

Za odkrivanju problemov IAQ moramo spremljati [7]:

— izdelavo začetne ocene stanja,

— vrednotenje pripomb ljudi iz objekta,

— meritve kakovosti zraka in toplotnega ugodja v prostorih,

— meritve delovanja klimatizacijskega sistema v poslopju,

— oblikovanje in uvedbo sprememb za izboljšanje IAQ,

— ponovno vrednotenje nastalega stanja.

2.1 Začetna ocena

V tej fazi je treba zbrati čim več podatkov o problematični stavbi in zdravstvenih težavah, ki jih navajajo ljudje. Do podatkov lahko pridemo, če se sestanemo z vodstveno ekipo in zastopniki ljudi, ki v njej delajo ali živijo, pregledamo razpoložljivo gradbeno in strojno dokumentacijo o poslopju, obhodimo poslopje in odkrivamo potencialne vire onesnaženja zraka, pregledamo strojne instalacije, delovanje klimatizacijskega sistema, kroženje zraka itn.

2 REVIEW OF STRATEGIES USED TO INVESTIGATE INDOOR AIR QUALITY

The investigation of indoor air quality problems is usually initiated by occupant complaints. These complaints are addressed to the owner or tenant of the building. One of these is responsible to reply to the occupants and explain to them what might be the reasons for the problems. The owner or tenant can obtain reliable information concerning the problem from the IAQ research team. In countries where occupant health and indoor comfort are of great value (in the USA for instance) the investigation of IAQ problems is considered to be a very serious process which usually results in enormous financial penalties for the building owner or tenant. IAQ knowledge and understanding will undoubtedly help to protect the building from IAQ problems already in the design stage.

The investigation of IAQ problems requires a multidisciplinary approach. The following experts would usually be invited to form a research team [6]:

— civil engineers, architects (physical building characteristics),

— mechanical engineers (HVAC system),

— medical professionals (type and extent of occupant health and comfort concerns),

— experts for industrial hygiene (quality of indoor air),

— sociologists (occupants' subjective perceptions of conditions).

During the investigation of IAQ problems the following six stages should be followed [7]:

— initial assessment,

— assessment of occupant concerns,

— IAQ and thermal comfort monitoring

— ventilation measurements,

— development and implementation of mitigation strategies,

— post-implementation assessment.

2.1 Initial assessment

In this stage as much information as possible about the building and reported health problems is to be gathered. We have three information sources: meetings with the building operator and occupant representatives, review of available architectural and engineering plans and walk-through inspection to identify pollutant sources, inspection of design configuration and operational conditions of the building's HVAC system, inspection of air intakes and exhausts etc.

2.2 Vrednotenje pripomb ljudi

Do uporabnih rezultatov pridemo s statistično obdelavo vprašalnikov. Iz rezultatov je mogoče sklepati o bolezenskih znakih, ki se največ pojavljajo, ter njihovo pogostost in prostorsko porazdelitev v poslopju. Slednje je zelo pomembno za kasnejše meritve onesnaženosti zraka v prostorih. Primeri takšnih anket v Sloveniji so bili v letih 1989 in 1991 izvedeni v objektu SOP Krško v Ljubljani. Ankete in kasnejše meritve je izvedel Laboratorij za ogrevalno, sanitarno in solarno tehniko na Fakulteti za strojništvo.

2.3 Meritve kakovosti zraka in toplotnega ugodja v prostorih

V prvi fazi izvedemo meritve naslednjih petih parametrov:

– ogljikov dioksid kot indikator zadostnosti prezračevanja,

– ogljikov monoksid kot indikator vstopa produktov zgorevanja v prostore,

– lebdeče delce v zraku kot indikator količine prahu v objektu in kakovosti filtriranja zraka,

– temperaturo zraka, relativno vlažnost in gibanje zraka kot osnovne indikatorje toplotnega ugodja v prostoru.

Pri tem je pomembna pravilna izbira merilnih mest (vse cone objekta, problematične lokacije), dolžina meritev (urni, dnevni, tedenski potek vrednosti, vpliv ustavitve klimatizacijskega sistema konec tedna) in njihova natančnost.

Če ugotovitve kažejo navzočnost še drugih snovi, izvedemo še meritve formaldehida, plesni in bakterij v zraku, radona, hlapnih organskih spojin, nikotina itn. Dobljene vrednosti koncentracij posameznih substanc je nato treba primerjati z dovoljenimi vrednostmi, ki jih predpisujejo standardi in normativi [5], [8].

2.4 Meritve delovanja klimatizacijskega sistema

Te meritve so zelo pomembne pri ugotavljanju vzrokov za probleme IAQ, saj je neprimeren ali slabo vzdrževan sistem za klimatizacijo zelo pogost vzrok slabega zraka. Pri tem merimo pretoke zraka na dovodnih rešetkah v prostor in odvodnih rešetkah. Učinkovitost prezračevalnega sistema preverjamo z »sledilnim plinom«. Pri meritvah v poslovnih objektih se pogosto uporablja žveplov heksafluorid (SF_6) ali ogljikov dioksid, kot manj natančna in cenejša varianta. Tako je mogoče raziskati tudi tokove zraka znotraj poslopja, npr. problem vdora ogljikovega monoksida z bližnjih parkirnih prostorov itn.

2.2 Assessment of occupant concerns

The useful data is usually collected using extensive questionnaire surveys filled out by occupants. The results from a questionnaire survey may be used to quantify the prevalence and type of health complaints, their frequency and spatial distribution within the building. The distribution of problematic locations is important in the development of the sampling protocols used in later stages. Extensive questionnaire surveys have been done in the SOP-Krško building in Ljubljana by the Laboratory for Heating, Sanitary and Solar Technology, Faculty of Mechanical Engineering.

2.3 IAQ and thermal comfort monitoring

In the first stage we monitor the following five parameters:

– carbon dioxide as an indicator of the adequacy of the outside air supply,

– carbon monoxide as an indicator of the infiltration of combustion byproducts,

– respirable suspended particles as an indicator of filtration effectiveness and the general dust loading of the indoor environment,

– temperature, relative humidity and air velocity as indicators of thermal comfort.

The following items should be carefully considered: selection of sampling locations (all HVAC zones, worst case locations), length of the measurements (hourly, daily, weekly pattern, the effect of weekend HVAC system shut-down) and the accuracy of the measurements.

If specific point sources of indoor pollution are identified from the investigation in previous stages, additional IAQ sampling may be undertaken. Followup measurements may include sampling and analysis of formaldehyde, airborne fungi and bacteria, radon, volatile organic compounds, nicotine etc. The results of the monitoring are compared to available standards and guidelines for threshold limit values [5], [8].

2.4 Ventilation measurements

Quantification of ventilation performance parameters is a very important stage since inadequate HVAC system performance has been implicated as a cause of many IAQ-related problems. Actions include airflow measurements to determine flows through the supply and exhaust openings in order to determine the ventilation rate. Ventilation effectiveness can be evaluated using a tracer gas technique. In commercial buildings a sulphur hexafluoride (SF_6) is usually applied as a tracer gas. The use of carbon dioxide is a simplified and less costly method than SF_6. Tracer gas technique may also be used to investigate the patterns of airflow within the building, for example to determine whether air from a parking garage is infiltrating the fresh air intakes.

2.5 Oblikovanje in uvedba sprememb za izboljšanje IAQ

Po ugotovitvi vzrokov za slab zrak v objektu določimo in izvedemo izboljšave. Predlagane izboljšave sporočimo lastniku ali upravniku objekta.

2.6 Ponovno vrednotenje stanja

Zadnji, a pomembni korak je ponovno vrednotenje stanja v poslopju, po opravljenih izboljšavah. Ponovno naj bi izvedli meritve kakovosti zraka in toplotnega ugodja v prostorih, se pogovorili z ljudmi in tako prišli do realne ocene uspešnosti izvedenih sprememb. Pogosto prav za ta korak zmanjka denarja, oziroma se zaradi zmanjšanja pritožb to preverjanje opusti, kar je nedopustno.

3 MOŽNOSTI ZA IZBOLJŠANJE IAQ

Za grobo ponazoritev vzrokov, ki privedejo do pojava bolnih stavb so zanimivi rezultati, ki jih je objavila ameriška organizacija Nacionalni inštitut bivališčne varnosti in zdravja (NIOSH) po pregledu več ko 500 poslopij, v katerih so se ljudje pritožili zaradi slabe kakovosti zraka v prostorih (sl. 2). V največ primerih je vzrok nezadovoljivo delovanje ventilacijskega ali klimatizacijskega sistema (52%), tj. lahko nepravilno načrtovan, neprimerno nastavljen ali pomanjkljivo vzdrževan sistem. Drugi ugotovljeni vzroki za slab IAQ so bili: viri onesnaženja znotraj poslopja (17%), onesnaženost zraka zunaj poslopja (11%), mikrobiološko onesnaženje (5%), oprema in pohištvo (3%). V 12 odstotkih primerov niso mogli ugotoviti vzroka za težave, kar nedvomno kaže na razmeroma veliko zapletenost reševanja problemov IAQ. Iz rezultatov je tudi razvidno, da je mogoče večino problemov IAQ rešiti ali preprečiti, če zagotovimo primerno količino svežega zraka ljudem v poslopjih.

2.5 Development and implementation of mitigation strategies

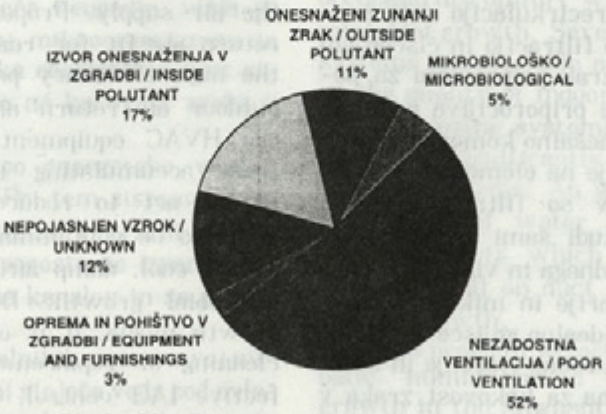
When the causes of the IAQ problems have been determined, retrofit actions to improve indoor environmental conditions must be developed and implemented. The recommended retrofit actions are reported to the building owner or operator.

2.6 Post-implementation assessment

A final, but important, stage is followup assessment after the retrofit implementation. The assessment should include the measurement of IAQ and thermal parameters, meeting with occupants, in order to determine the effectiveness of the retrofit actions. This stage is rarely possible due to budgetary constraints or is omitted because of decreased occupant complaints, which is intolerable.

3 GUIDELINES FOR IMPROVED IAQ

For a better understanding of the causes for a sick building the results published by the National Institute for Occupational Safety and Health (NIOSH) and based on evaluation of more than 500 buildings with IAQ problems in the USA (Fig. 2) may be interesting. According to these findings, inadequate ventilation was identified as the primary cause of IAQ problems (52%). Reasons for this are a poorly designed, unbalanced or improperly maintained ventilation system. Other identified causes include: contamination from specific indoor sources (17%), infiltration of outdoor contaminants (11%), contaminants from building materials and interior furnishings (3%) and microbial contamination (5%). An illustration of the complexity of investigating IAQ problems is the finding that the cause could not be determined by the investigators in 12% of the buildings being investigated. It is obvious that most IAQ problems could be solved if we simply provide adequate ventilation to the building occupants.



Sl. 2. *Vzroki za nastanek bolnih poslopij*
Rezultate je objavil Nacionalni inštitut bivališčne varnosti in zdravja, ZDA

Fig. 2. *Causes for sick building syndromes*
Published by National Institute for Occupational Safety and Health, USA

V nadaljevanju bomo opisali nekaj ključnih točk, na katere bodo morali biti projektanti v prihodnosti še posebej pozorni.

3.1 Zadostna količina dovedenega svežega zraka

To bo verjetno najpomembnejša sprememba, ki jo bodo prinesli novi standardi. V poslopja bo treba dovesti primerne količine svežega zraka. Predpisane količine bo pri načrtovanju in gradnji treba spoštovati, če se bomo hoteli izogniti kasnejšim težavam ali celo sodnim postopkom.

V Sloveniji je že dolgo predpisana urna izmenjava zraka, ki znaša 0,7-kratno vrednost bruto prostornine prostora. To je približno enako enkratni izmenjavi zraka, če računamo z neto prostornino prostora. Če je potreba po večji izmenjavi zraka, je zagotovljena rekuperacija toplote, kar preprečuje, da bi projektanti uporabljali mešalne komore kot rekuperacijske naprave.

3.2 Zajemi svežega zraka in izpusti slabega zraka

S pravilno lego odprtin za zajem svežega zraka lahko zelo zmanjšamo potrebe po čiščenju. Zajem zraka naj ne bo v bližini odprtin za odvod slabega zraka, restavracij, prometnih cest, parkirišč, bencinskih črpalk, odlagališč odpadkov, hladilnih stolpov, stoječe vode in podobnega. Pametno je upoštevati nezasedene površine v neposredni bližini, glede na to, kakšen tip objekta se tam lahko pojavi v prihodnosti, in zajemati zrak visoko nad tlemi, vsaj v višini tretjega ali četrtega nadstropja.

3.3 Filtriranje zraka

Ker je uporaba samo svežega zraka za klimatizacijo cenovno nesprejemljiva, večina klimatizacijskih sistemov omogoča recirkulacijo dela prostorskega zraka. S pravilno filtracijo in čiščenjem prostorskega zraka lahko zrak pripravimo za ponovno uporabo. Vsekakor je priporočljiva postavitev učinkovitih filtrov za mešalno komoro, da preprečimo nabiranje umazanije na elementih klimatizacijske naprave. Čeprav so filtri namenjeni čiščenju zraka, so lahko tudi sami vir nečistoč, ko so izpostavljeni toku hladnega in vlažnega zraka in se na njih pojavijo bakterije in mikrobi. Umazanija in vlaga sta namreč idealno gojišče. Ni treba posebej poudarjati, kako sta redno čiščenje in redna zamenjava filtrov pomembna za kakovost zraka v poslopju. Prav tu veliko vzdrževalnih služb nekorektno opravlja svoje delo, pogosto zaradi pomanjkanja denarja, včasih pa zaradi malomarnosti. Filtracijo pred vstopom v prostor uporabljamo pri

Some key design points will be discussed now to which the future HVAC system designers will have to pay much attention.

3.1 Adequate ventilation rate

This will likely be the most important change that ventilation standards will bring. Buildings will have to be supplied with adequate fresh air. The ventilation rates specified by standards will have to be respected at the stage of building design to avoid later occupant complaints or even lawsuits.

These problems are a little less severe in Slovenia because for a long time the ventilation rate of 0.7 ach (air changes per hour) in terms of gross building volume has been required. In terms of net building volume this would be about 1.0 ach. If greater ventilation rates have been needed for specific applications, heat recovery has been required. This prevents the engineers from using economizer systems as heat recovery.

3.2 Outdoor air intakes and exhaust openings

The proper location of fresh air intakes reduces the need for air cleaning. Air intakes should not be located close to exhaust air opening locations, close to the restaurants, roads with heavy traffic, parking garages, petrol stations, garbage dumps, cooling towers, standing water or similar. Nearby undeveloped lots should be considered with respect to the type of business that may appear there in the future. Outdoor air intakes should be located high enough, at least on the third or fourth floor.

3.3 Air filtration

Since one hundred percent outdoor air ventilation is not cost effective, the majority of the HVAC systems recirculate a portion of the air supply. Proper air filtering makes the return air fit for reuse. It is advisable to put the high efficiency particulate filters after the outdoor air/return air mixing box and before the HVAC equipment to prevent contaminants from accumulating in the equipment. While filters act to reduce air contaminants, they can also be contaminant producers. When exposed to cool, damp air they become a source of microbial growth. Dirt and moist are ideal growth media. It is evident that frequent filter cleaning or replacement are essential for effective IAQ control. And this is where many maintenance teams do their jobs poorly: often because of budgetary constraints, sometimes due to negligence. In some cases air filtration can be divided into two stages: with the first

velikih zahtevah po čistoči zraka (bolnišnice, laboratoriji). Filtracijo lahko izvedemo tudi v dveh stopnjah, prvo stopnjo v klimatizacijski napravi, drugo stopnjo pa z zelo učinkovitimi filtri za lebdeče trdne delce (HEPA) pred vstopom zraka v prostor. Ti filtri imajo moč filtracije submikronskih delcev (premer 0,3 mikrometra) 99,97% in so primerni za filtracijo dima, atmosferskega prahu, bakterij in mikrobov. Filtracija onesnaževalnikov v plinasti obliki in vonjav zahteva uporabo filtrov iz aktivnega oglja. Na tržišču se pod znanim imenom IAQ pojavljajo naprave, ki jih trgovci ponujajo kot idealno rešitev za čiščenje zraka v prostoru z uporabo ozona (O_3). Ozon je reaktiven plin, ki ima jedek vonj in povzroča pri kratkotrajnejši izpostavljenosti večjim koncentracijam draženje dihalnih organov in prehodno poslabšanje delovanja pljuč. Takšni generatorji ozona nimajo vgrajene regulacije in lahko koncentracijo ozona v prostoru dvignejo nad zdravo mejo, zato moramo biti pri nakupu in uporabi previdni [10].

3.4 Vgradnja zdravju neškodljivih materialov

Do velikih sprememb prihaja pri zahtevah po vgradnji gradbenih materialov notranje opreme, ki ne sproščajo zdravju škodljivih snovi, saj notranji viri onesnaženosti zraka botrujejo približno 17 odstotkom bolnih poslopij. V pripravi so predpisi za emisijo škodljivih snovi v temperaturnem območju od -20 °C do 30 °C. Predpisi bodo zajemali izolacijske materiale, talne in stenske obloge, zavese, lepila, barve in lake, veziva, topila, plastične mase itn. Projektanti bodo morali poznati in upoštevati te predpise.

3.5 Ovlaževalniki zraka

Človek se v prostoru ugodno počuti, če je relativna vlaga v področju od 30 do 60 odstotkov. Nižja relativna vlaga povzroča neugodje, višja pa povečuje možnosti za razvoj mikroorganizmov in bakterij. Za ovlaževanje zraka obstaja več vrst sistemov, ki različno vplivajo na kakovost zraka v prostoru.

Razprševalni sistemi so energetsko varčni, imajo pa slab vpliv na IAQ. Pri tem sistemu skozi šobe drobno razpršujemo vodo v zračni curek. Drobne kapljice, ki v zraku pogosto ne izparijo popolnoma, se usedajo na stene kanalov in so potencialno gojišče mikrobov.

Pri adiabatskih ovlaževalnikih so za razvoj mikroorganizmov problematični stoječa voda pod ovlaževalnikom in usedlina mineralov iz vode in soli, namenjena mehčanju vode, ki se nabira na mediju, na katerem izpareva voda. To so ovlaževalni sistemi, ki jih iz higienskih razlogov ne priporočamo več.

filtration stage in the central air handling unit and the second filtration using high efficiency particulate (HEPA) filters, just before the air enters the space. Air filtration just before entering the space is used for high air quality requirements (clean rooms, operating theatres, laboratories). HEPA filters have the removal efficiency of 99.97% for particles with diameter of 0.3 micrometer and are suitable for fumes, atmospheric dust, bacteria and microbe filtration. A variety of indoor air cleaners with ozone generators are gaining increased popularity on the IAQ market. Ozone (O_3) is a highly reactive gas that has a pungent odour. Short-term exposure to elevated concentrations cause irritation of the respiratory tract and a temporary decrease in lung function. Since the ozone generators available on the market are usually not equipped with regulators preventing the ozone buildup beyond the threshold limit values a buyer should be careful in the selection and use of these devices [10].

3.4 The use of low-emission materials

The requirements concerning low-emission building and furnishing material use are undergoing major changes since indoor pollutants cause about 17% of all sick building syndromes. The existing standards for pollutant emission are now being revised for the temperature range from -20° C to 30° C. These standards will cover insulation materials, materials for floor and wall carpets, curtains, glues, paints and varnishes, adhesives, solvents, plastics etc. The designers and engineers will be required to have a sufficient knowledge of indoor pollutants, its sources and their threshold limit values.

3.5 Humidification systems

Adequate indoor air quality requires the indoor air humidity to be kept between about 30% and 60% relative humidity. Lower levels cause occupant discomfort while higher levels promote microbial growth. Several types of humidification systems are available and all have varying affects on the quality of indoor air.

Atomizing systems are energy-efficient but they can significantly contribute to indoor air quality problems. An atomizing system injects a fine spray of water into the airstream. Tiny water droplets which sometimes do not fully evaporate fall on duct surfaces and promote microbial growth.

The problem associated with the use of adiabatic humidification systems are: microbial growth in the stagnant water in the pan included in this type of unit, and mineral and dirt deposits at the media where the water evaporates. These humidification systems are not recommended for sanitary reasons.

Bolj zdravi in zato primernejši so ovlaževalniki, ki zračni tok vlažijo z vročo vodno paro. Če za pridobivanje pare uporabimo elektriko, so žal energetsko bolj potratni, zagotavljajo pa najbolj neoporečno vlaženje zraka. Pri parnem ovlaževanju ne prihaja do razvoja mikroorganizmov in bakterij.

Lahko pa uporabljamo tudi adiabatske ovlaževalnike s piezoelektričnim razprševanjem ali pnevmatskim razprševanjem sveže pitne vode.

3.6 Porazdelitev zraka v prostoru

Pravilna porazdelitev zraka v prostoru omogoča dovod zadostne količine svežega zraka v območja, kjer so ljudje, in z metodo razredčevanja ali odplakovanja zmanjšuje onesnaženost prostorskega zraka.

Najvišjo stopnjo čistosti zraka v prostoru dosežemo z načinom porazdelitve, ki se običajno uporablja v posebno čistih prostorih ali operacijskih dvoranah. Tu zrak vstopa v velikem številu laminarnih curkov prek celotne površine stropa ali operacijske kabine navpično navzdol, odprtine za odsesovanje zraka iz prostora so montirane v tleh. Smer zraka je lahko tudi obrnjena, da ob velikih toplotnih obremenitvah v prostoru (računalniške sobe) dosežemo stabilnejše zračne tokove. Seveda so to najdražji sistemi ventilacije.

V praksi so najpogostejši sistemi, kjer zrak vstopa in izstopa na stropu. Pri tem se sveži zrak v zgornjem delu prostora meša s prostorskim, prihaja v bivalno cono in nato izstopa skozi izstopne odprtine. Dovedene količine zraka so tu manjše, zato so tudi stroški priprave in distribucije zraka manjši. Manjša je tudi učinkovitost prezračevanja, saj škodljive snovi v prostoru pretežno mešamo.

Sistemi z indukcijskimi ali ventilatorskimi konvektorji so na slabem glasu, saj so pri njih pogosto velike težave s kakovostjo zraka v prostorih, zaradi mešanja prostorskega zraka s svežim in pomanjkljivega filtriranja. Te sisteme bi lahko izboljšali s poznejšo namestitvijo HEPA in elektro statičnih filtrov. Problematična je tudi prevelika šumnost teh naprav.

V zadnjem času je vedno več rešitev z lokalnim dovodom svežega zraka na delovno mesto, s čimer povečamo prilagodljivost prezračevalnega sistema v primeru spremembe namembnosti prostora in možnost nastavitve količine zraka glede na trenutne potrebe človeka. V Laboratoriju za ogrevalno, sanitarno in solarno tehniko na Fakulteti za strojništvo v Ljubljani v okviru raziskovalnega dela razvijamo osnutek takšne prezračevalne naprave. Minimalno količino svežega zraka, ki je tudi prenosnik toplote ali hladu, dovajamo prek kanalov v dvojnem podu ali spuščenem stropu do posameznega delovnega mesta.

Healthier and thus more preferred are steam humidification systems which inject moisture into the airstream in a vapour form. Unfortunately electric systems for producing water steam are the most expensive but they provide the best sanitary operation since the vapour supports no microbial growth.

The adiabatic humidification systems where tap water is atomized by piezo-electric or pneumatic devices are also recommended.

3.6 Room air distribution

The appropriate room air distribution provides the occupant zone with the sufficient amount of fresh air. Based either on dilution or piston ventilation principle the appropriate room air distribution removes the contaminants from the room air.

The highest removal rate of room contaminants is achieved by displacement distribution or once-through flow which is usually employed in clean rooms and operating theatres. The air enters the room in laminar jets from many small openings all over the laminar panels on the ceiling or operating cabin within the theatre. The exhaust openings are located on the floor. The inverse distribution of air, distribution from the bottom to the top, is particularly suitable for rooms with a high accumulation of heat (computer centres). This results in more stable convective currents. These are the most costly room air distribution systems.

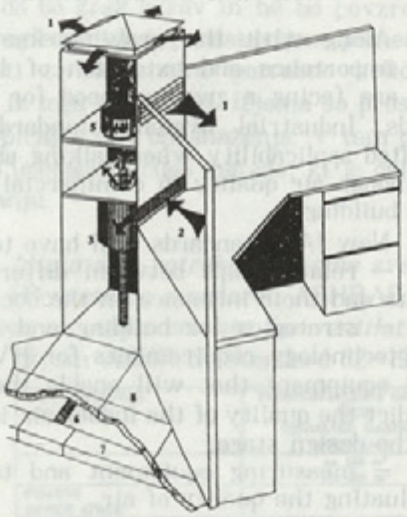
The most common room air distribution system is the one where the air enters the room and is exhausted from the room at the ceiling. The entering fresh air in the upper part of the room mixes intensively with the room air, then enters the occupant zone and finally leaves through the exhaust openings at the ceiling. These systems use less fresh air than displacement ventilation so the costs of air handling and distribution are lower. The ventilation effectiveness is lower because the contaminants are not washed away but mixed.

Induction and fan coil units often fall short in maintaining adequate indoor air quality because they intensively mix fresh air and room air without adequate filtration. These systems could be retrofitted and thus improved in their IAQ performance by installation of HEPA and electrostatic filters. These systems also have many problems with elevated noise level.

Recently, a growing number of applications have been developed for breathing zone air distribution systems. Such systems increase the flexibility of ventilation systems when the workplaces in the room are rearranged and they enable the occupants to adjust the amount of fresh air according to their temporary needs. In the Laboratory for Heating, Sanitary and Solar Technology at the Faculty of Mechanical Engineering, we are developing such ventilation systems as a part of our research work. Fresh air, which also compensates the heating or cooling loads, is delivered to each occupant through ductwork which can be located beneath a raised floor or above a false ceiling.

To omogoča veliko gibčnost in prilagodljivost, če se spremeni namembnost prostora. Masa zraka je omejena, razlika temperature pa je lahko ustrezno večja (do 45 °C pri ogrevanju, do 5 °C pri ohlajanju). Za prezračevanje in pokrivanje toplotnih dobitkov v poletnem obdobju je zanimiv razvod centralno pripravljenega, zelo hladnega zraka (5 do 7 °C). Stroški priprave tako hladnega zraka so pri uporabi akumulacije z ledom nižji. Cenejši je tudi razvod zraka. Problematična pa sta kondenzacija na stenah razvodnih kanalov in izvedba vpihovanja v bližini človeka. Preden hladni zrak doseže človeka, se mora pomešati s toplejšim, prostorskim (sekundarnim) zrakom. Tega je pred mešanjem treba očistiti, zato ga vodimo prek filtrov HEPA in aktivnega oglja. Vonjave in lebdeče prašne delce torej čistimo pri samem viru, neposredno pri človeku (sl. 3).

This enables great flexibility and adaptability in case of room rearrangement. The quantity of air is limited so accordingly the temperature difference may be higher (up to 45 °C for heating and 5 °C for cooling). Cold air distribution systems (5 to 7 °C) with a central air handling unit are increasingly attractive for ventilation and cooling in summer. If combined with low temperature thermal storage (ice storage) the costs for air handling distribution are lower. The potential for condensation in ducts and introduction of low temperature air within occupant's micro-climate are major concerns with cold air delivery systems. Before the cold air enters the occupant's micro-climate it has to be mixed with warmer, room (secondary) air. Before mixing place the secondary air has to be cleaned, so it passes through the HEPA and activated carbon filters. This way the odours and respirable suspended particles get filtered at their source – the occupant (Fig. 3).



1 - DOVOD ZRAKA / SUPPLY AIR
2 - PROSTORSKI ZRAK / ROOM AIR
3 - PAKET TREH FILTROV (PREDFILTER, FILTER Z AKTIVNIM OGLJEM, HEPA FILTER / THREE STAGE FILTERING DEVICE (PRE-FILTER, CARBON FILTER, HEPA FILTER)
4 - CENTRALNO PRIPRAVLJEN SVEŽI ZRAK / FRESH AIR FROM CENTRAL AIR HANDLING UNIT
5 - VENTILATOR / VENTILATOR
6 - FLEKSIBILNA CEV / FLEXIBLE PIPE
7 - KANAL ZA RAZVOD ZRAKA / SUPPLY AIR DUCT
8 - DVOJNI POD / RAISED FLOOR

Sl. 3. *Osnutek lokalne oskrbe delovnega mesta s svežim zrakom in filtriranjem prostorskega zraka*
Fig. 3. *The concept of breathing zone air distribution system with room air filtration*

3.7 Vlažni hladilniki zraka

Ti so zaradi kondenzacije zračne vlage na njihovi površini vlažni. Kadar ni izločevalnika kapljic mora biti hitrost toka zraka omejena, da omejimo raznos kapljic kondenzata iz prenosnika toplote v smeri toka zraka. Odtok kondenzata iz zbiralnika v kanalizacijo mora biti pravilno speljan in mora imeti zaporo za smrad. Zbiralnik pod hladilnikom naj bi v smeri toka segal vsaj še en meter za hladilnikom, da zbira vodne kapljice.

3.8 Hladilni stolpi

To so klasični viri in življenjski prostor za alge, gljivice, v skrajnih primerih tudi bakterije, ki povzročajo legionarsko bolezen. Legionarsko bolezen so prvič odkrili leta 1973 v vodi hladilnih stolpov hotela v Philadelphiji, ZDA, kjer je imela letno srečanje Zveza ameriških legionarjev. Nekaj dni po srečanju so se pri mnogih udeležencih pojavili nenavadni bolezenski znaki (glavobol, vročina, bolečine v mišicah) in nazadnje je od 212 udeležencev

3.7 Wet cooling coils

They are wet because of moist air condensation on the coil surface. If not equipped with a drain pan, the coil face velocity should be limited to limit moisture carryover. The condensate trap should eliminate stagnant water and has to be equipped with a U-trap. The drain pan should extend at least one meter over the coil in order to collect as much water as possible.

3.8 Cooling towers

Cooling towers are classical reservoirs of algae, fungi and in some cases bacteria which causes legionnaires' disease. Legionnaires' disease was reported for the first time in Philadelphia in 1973. The bacteria was actually found in cooling tower water next to hotel where the American Legion had a meeting. A few days after the participants attended the meeting many of them developed an illness with unusual symptoms (headache, high fever, muscular aches) and ultimately 34 of 212 people died. Later many other sporadic

kar 34 ljudi umrlo. Kasneje je bilo registriranih še več podobnih primerov okužbe. Okužba se prenaša prek aerosolov v toku zraka klimatizacijskega sistema. Ker je bolezen težko diagnosticirati, obstaja verjetnost, da je bilo primerov teh obolenj še mnogo več. Raziskave so pokazale, da je razvoj bakterij legionele v vodi možen v temperaturnem območju med 17 °C in 60 °C, z optimalno temperaturo za razmnoževanje med 35 °C in 37 °C [11]. Priporočljivo je, da hladilni stolpi delujejo pri najnižji temperaturi, ki jo še dopuščajo omejitve hladilnega procesa in temperatura vlažnega termometra okoliškega zraka. Okužba vode v hladilnem stolpu je zelo resen problem, ki terja reden nadzor temperature vode v takšnih napravah in po potrebi dekontaminacijo. Stolpi naj bodo postavljeni daleč od odprtin za zajem svežega zraka ali področij zadrževanja ljudi.

4 IAQ IN STANDARDIZACIJA

Hkrati z razvojem znanja o pomembnosti in razsežnostih problematike IAQ se zvečuje tudi potreba po ustrezni standardizaciji za to področje. Standardi za področje industrijske higiene imajo omejeno uporabnost, ko gre za sodobna spoznanja o kakovosti zraka v poslovnih in stanovanjskih objektih.

Novi standardi bodo zajemali naslednja področja:

— vzajemni vpliv različnih vzrokov onesnaženosti na človeka v prostoru,

— strategije načrtovanja poslopja in sistema prezračevanja ter tehnološke zahteve uporabljene opreme in regulacijske tehnike, ki bodo projektantom zagotavljale kakovosten zrak v takšnem poslopju,

— merilni instrumenti in merilna tehnika za ocenjevanje kakovosti zraka,

— metode testiranja in ocenjevanja opreme za zagotavljanje kakovosti zraka.

Najobsežnejše delo na področju standardizacije so do danes opravile institucije: Mednarodna organizacija za standardizacijo (ISO), Evropski komite za standardizacijo (CEN) in Ameriška zveza za ogrevanje, hlajenje in klimatizacijo (ASHRAE). Uporaba standardov ISO ni obvezna, standarde CEN pa je treba uporabljati v vseh evropskih državah. Kadar je to mogoče, skuša CEN prevzeti standarde ISO. Ameriški nacionalni standardizacijski institut (ANSI) običajno prevzame standarde ASHRAE. Pred kratkim je ANSI/ASHRAE prevzel skrb nad tehničnim komitejem ISO/TC205 »bivanjski prostor v poslopjih«. ASHRAE predlaga, naj novi standard temelji na sedanjih standardih ASHRAE Standards 55, 62 in 90.

Najpomembnejši standard za področje ventilacije in kakovosti zraka v prostoru je ANSI/ASHRAE Standard 62-1989 [8]. Glede na napovedi lahko v letu 1995 pričakujemo

cases and epidemics were reported. The legionellae are transferred to humans by aerosols through the ductwork of an air conditioning system. However, since the disease is difficult to diagnose, it is probably underreported. Research [11] shows that colonization of cooling towers by legionella bacteria requires water temperatures between 17 °C and 60 °C, with an optimum temperature range for multiplication from 35 °C to 37 °C. It is recommended that the cooling water systems operate at as low a temperature as is practicable within the constraints of refrigeration system characteristics and ambient wet-bulb temperature. The colonization of cooling towers is a very serious problem which requires a constant water temperature monitoring and decontamination on demand. Cooling towers should be located as far as possible from all building intakes and places intended for use by people.

4 IAQ AND STANDARDIZATION

Along with the growing knowledge about the importance and extension of IAQ problems we are facing a growing need for proper standards. Industrial hygiene standards have only limited applicability when talking about problems of indoor air quality in commercial and residential buildings.

New IAQ standards will have to focus on:

— relationships between different contaminants and their influence on the occupants,

— strategies for building and HVAC design and technology requirements for HVAC and control equipment that will enable the engineer to predict the quality of the indoor air in the building at the design stage,

— measuring equipment and techniques for evaluating the quality of air,

— methods for testing and rating of equipment for providing indoor air quality.

The most significant standardization work is now being done by the International Organization for Standardization (ISO), the European Committee for Standardization (CEN) and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). While ISO standards are not mandatory, CEN standards must be followed in all European countries. Whenever possible, CEN attempts to adopt existing ISO standards instead of developing new standards. The American National Standard Institute (ANSI) adopts ASHRAE standards for its standards. Recently ANSI/ASHRAE obtained the secretariat of the new ISO technical committee ISO/TC205 "Building Environmental Design". ASHRAE suggests that this work be based on ASHRAE standards 55, 62 and 90.

Today, the most important standard for ventilation and indoor air quality is ANSI/ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality [8]. According to information, this standard in now being revised and we may expect the new version to be available in 1995.

izpopolnjeno verzijo tega standarda. V standardu je sprejemljiva kakovost zraka, definirana kot zrak, ki ni onesnažen nad dovoljenimi mejami, ki jih določijo za to pooblaščene institucije in hkrati zrak, za katerega vsaj 80 odstotkov ljudi ne izrazi nezadovoljstva. Ta definicija zadostuje zdravstvenim zahtevam in zahtevam ugodja.

Standard ASHRAE predpisuje dve metodi za določitev potrebne količine svežega zraka.

Metoda, ki predpisuje količino svežega zraka v prostoru, je primerna za vsaj 95% klimatizacijskih naprav v praksi. Predpisuje potrebno količino svežega zraka v litrih/s na osebo za prostore različnih namembnosti (včasih tudi litrov/s na m^2 prostora). Metoda temelji na upoštevanju stopnje zasedenosti prostora z ljudmi in predpostavlja, da bo predpisana količina dovedenega svežega zraka razredčila koncentracijo onesnaženosti zraka do takšne mere, da bo zrak zdrav in ne bo povzročal neugodja. V preglednici 1 so predstavljene pomembnejše vrednosti za minimalne potrebne količine svežega zraka iz tega standarda. Izjema so prostori, kjer so neobičajni viri onesnaženja. V tem primeru moramo uporabiti drugo metodo, ki je opisana v nadaljevanju.

ASHRAE Standard 62 defines acceptable indoor air quality as air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction. This definition includes both health and comfort requirements.

The ASHRAE Standard specifies two procedures for estimating the required amount of outdoor air.

The ventilation rate procedure is used when designing 95% of heating, ventilating and air-conditioning (HVAC) systems. This method specifies the amount of outdoor air in litres/s per person for different types of spaces (in some cases in litres/s per m^3). The ventilation rate in this procedure is based mainly on the occupancy level, and it is assumed that this rate dilutes the air pollutants to a concentration that will not be harmful or cause significant discomfort to the occupants. In Table 1 the ventilation rates for some typical spaces based on this standard are presented. The exception are the areas where unusual indoor contaminants are present. In such cases the second method from this standard should be applied.

Preglednica 1: *Minimalne potrebne količine svežega zraka za prezračevanje*
(Povzeto po standardu ASHRAE 62—1989, preglednica 8)

Table 1: *Outdoor air requirements for ventilation*
(From ASHRAE Standard 62—1989, Table 8)

VRSTA PROSTORA APPLICATION	PREDPOSTAVLJENA GOSTOTA LJUDI ESTIMATED MAXIMUM OCCUPANCY	MINIMALNA KOLIČINA SVEŽEGA ZRAKA OUTDOOR AIR REQUIREMENTS	
	na 100 m^2 per 100 m^2	l/s na osebo l/s per person	l/s na m^2 l/s per m^2
PISARNE OFFICE SPACE	7	10	-
KONFERENČNE DVORANE CONFERENCE ROOMS	50	10	-
AVLE RECEPTION ARENAS	60	8	-
RAZREDI, PREDAVALNICE CLASSROOMS	50	8	-
LABORATORIJI LABORATORIES	30	10	-
KNJIŽNICE LIBRARIES	20	8	-
AVLE (KAJENJE DOVOLJENO) SMOKING LOUNGES	70	30	-
HODNIKI CORRIDORS	-	-	0.25
JAVNA STRANIŠČA PUBLIC RESTROOMS (l/s per WC or l/s per urinal)	-	25	-
HOTELSKE SOBE HOTEL BEDROOMS (l/s per room)	-	-	15
BOLNIŠKE SOBE PATIENT ROOMS	10	13	-

Metoda, ki predpisuje kakovost zraka v prostoru, določa kakovost zraka z nadzorom vseh znanih onesnaževalnikov zraka in dovodom tolikšne količine svežega zraka, da so koncentracije snovi pod predpisanimi mejami. Za korektno uporabo te metode je treba poznati, kateri so bistveni onesnaževalniki zraka, kolikšne so priporočene mejne vrednosti in kolikšne so jakosti virov posameznih snovi znotraj objekta. Množičnejša uporaba te metode v prihodnosti bo korak v pravilno smer pri zagotavljanju kvalitetnejšega zraka v poslopjih.

In the indoor air quality procedure, acceptable air quality is achieved by controlling known contaminants and by introducing the amount of clean air necessary to bring the concentration of contaminants below recommended limits. To be able to use this procedure effectively, more information is needed on the relevant contaminants, the recommended limit values and the emission rates for typical building materials and furnishings. The wider use of indoor air quality procedures will be a step in the right direction in terms of providing indoor air of higher quality.

5 EKONOMSKI IN PRAVNI VIDIKI IAQ

Cena enega samega dne, ko je človek bolan zaradi slabega zraka, je lahko enaka ceni energije, ki bi bila porabljena na delovnem mestu tega človeka v obdobju šestih mesecev. V ZDA ugotavljajo, da letni stroški zdravljenja bolezni zaradi slabega zraka v poslopjih dosegajo ogromne vrednosti [1], [13]. Če k temu dodamo še stroške zaradi odsotnosti delavcev na delovnem mestu v času zdravljenja oziroma nadomeščanja, dobimo celotno ceno, ki jo je treba plačati na račun posledic slabega zraka. Nobenega razloga ni, da bi analize pri nas doma pokazale bistveno boljše stanje. Razlika je le v številu klimatiziranih poslopij.

V državah, kjer pravni sistem dejansko ščiti ljudi, njihovo zdravje in udobje, kjer lahko ljudje v primeru zdravstvenih težav zaradi slabe kakovosti zraka v prostoru tožijo lastnike ali upravitelje poslopij in tudi izterjajo odškodnino, bo poznavanje problematike IAQ pomembno za projektante, inženirje, posrednike ter lastnike in vzdrževalce stavb. Nepoznavanje bo ogrozilo njihov poklicni ugled ali jim v primeru tožbe na sodišču naložilo izredno visoke stroške odškodnine.

V ZDA že ugotavljajo, da je najcenejše, če se tožbam izognejo tako, da poskrbijo za kakovosten zrak v poslopjih. Najdražje je plačati odškodnino za utrpele zdravstvene težave ljudi; in v sodnem procesu je tisti, ki mora ob pomoči pravnikov dokazovati, da njegov ventilacijski in klimatizacijski sistem nista bila vzrok za nastale težave, v bistveno slabšem položaju od tistega, ki toži [14]. V izogib potencialnim tožbam bodo morali biti projektanti, izvajalci in lastniki zelo pozorni na tisti del vsebine pogodb in oglasov, ki se bo nanašal na obveznosti glede kakovosti zraka v poslopjih.

6 SKLEP

Kakovost zraka v prostoru je sporno vprašanje, kateremu bo v prihodnosti posvečena velika pozornost. Zavest ljudi in pozornost, ki ga IAQ namenjajo mediji, bo ta problem povezalo z oblikovanjem, delovanjem in vzdrževanjem poslopij ter sistemov za klimatizacijo v njih. Rešitve problema si vpleteni ne bodo mogli predajati iz rok v roke, kakor je bila to navada do sedaj. Zaradi kompleksnosti IAQ se bo treba razpoznavanja problemov in njihovega reševanja lotiti vsesplošno.

Neupoštevanje teh problemov bo poleg ogrožanja zdravja ljudi v poslopju ogrozil poklicni ugled odgovornih, v pravno urejenih državah pa jim bo naloženo plačilo izjemno visokih odškodnin in kazni za zanemarjanje odgovornosti.

5 ECONOMICAL AND LEGAL ASPECTS OF IAQ

The cost of one sick-day due to indoor air quality problems can equal the cost of energy for that one person's space for up to six months. The available data from the USA show that the annual costs for medical care for major illness resulting from poor IAQ are reaching enormous amounts of money [1], [13]. Adding the costs for lost productivity or temporary replacement of workers makes the total price that is to be paid for poor indoor air quality. There is no obvious reason for the situation in Slovenia to be much different from the one in the USA. The only difference is the number of buildings equipped with air-conditioning systems.

In countries where the legal system effectively and actually defends the occupants, their health and indoor comfort, counties where occupants actually have a power to sue the building owner or tenant in case of poor indoor air quality, the appropriate level of IAQ knowledge and understanding will be required for building designers, engineers, contractors, building owners and maintenance personnel. In case of deficient knowledge they may lose their professional credibility or be sued and charged for monetary compensation and legal costs.

In the USA they are facing the fact that the cost of preventing IAQ complaints is far less than the cost of going to court over the air quality. The most expensive solution to IAQ lawsuits for the building owner is to be charged for monetary compensation for occupants' health problems. The one on trial who has to prove that his building and HVAC system didn't cause the injury or damage has usually a much worse position in the trial than the plaintiffs [14]. In order to avoid possible IAQ lawsuit, the designers, engineers and building owners will have to be very careful about those parts of their contracts and advertising that deal with IAQ responsibilities.

6 CONCLUSION

Indoor Air Quality (IAQ) is an issue that will continue to gain prominence in the future. Public awareness and media attention will make IAQ an issue to be integrated into the design, operation and maintenance of a building and its HVAC system. In finding a solution to the IAQ problem, all involved parties will no longer play a "hot potato" game, the way they have until recently. Because of the complexity of the IAQ problems a multidisciplinary approach will be required for IAQ problem identification and elimination.

Being negligent in solving IAQ problems will, besides threatening the occupants' health, threaten the professional credibility of all those who will be recognised as being responsible. In countries where the legal system effectively and actually defends the occupants, such people will be charged high penalties for the claim of negligence.

Že danes prevladujeta mnenje in praksa, da je s primernim načrtovanjem in vzdrževanjem ceneje preprečevati nastanek slabega zraka, kakor pa za nastalo škodo plačevati odškodnino. Pri reševanju IAQ si lahko veliko obetamo od standardov, ki so ta čas že v fazi nastajanja in na katere se bodo lahko oprli projektanti pri izdelavi novih načrtov.

Today general opinion and practise show that it is much cheaper to prevent IAQ problems than pay monetary compensation for occupants' health problems and legal costs. For the future strategy for solving IAQ problems, the engineers may expect much help coming from new standards which are now being developed. They will be able to rely on these standards in the process of designing new buildings.

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