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The co-influence of noise and carbon dioxide on humans in the work and living environment

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Abstract. The aim of the paper is to investigate the co-influence of noise and carbon dioxide on people in different situations (inside/outside houses/classrooms) depending on the traffic intensity, the fuel used for heating in residential buildings etc.). All the measurements and the questionnaire have been carried out during the autumn of 2019 (at the mean temperature of 5–10 °C). Riga has a more intensive traffic compared to Tallinn and has greater problems of exceeding the permissible noise levels. The levels of carbon dioxide inside classrooms are also very high in Latvia (1,500–2,000 ppm). The concentration of carbon dioxide outside buildings is low in the forest areas (measured in the south of Estonia), being 340–350 ppm. In regional towns, it is 500 ppm (measured in autumn-winter near a busy street). The co-influence of noise and carbon dioxide on the residents has been investigated by using the Weinstein questionnaire. High carbon dioxide levels cause fatigue. Although it was not particularly pointed out by the residents questioned in a panel house with small apartments, the air was considered to be stuffy. The house is situated near a busy street, so the problems with noise are higher. ANOVA statistics has been used for the questionnaire ($p < 0.001$, $\alpha = 0.93$). The decrease of noise and carbon dioxide levels help people stay healthy and the environmental impact from the investigation is emphasising the necessity and providing possibilities to decrease the concentration of CO_2 in the ambient air.

Key words: environmental noise, carbon dioxide, risk assessment.

INTRODUCTION

Environmental noise is accumulation of the noise pollution created outdoors. This noise can be produced by transport, industrial and entertaining undertakings. Noise is frequently defined as an 'unwanted sound'. Within this context, environmental noise is mostly available in some form in all zones of human, animal or environmental activities. The special effects in individuals of exposure to environmental noise may differ from sensitive to physiological and psychosomatic (Job, 1988; Guidelines…, 2000; Kivikangur, 2016).

The reduction of the carbon dioxide concentration in the environmental air is an incredible task for innovative people today. One of the origins of carbon dioxide is road transport and avoiding the usage of public transport (electric-based etc.), giving preference to personal cars. This is also causing high noise levels in the outside environment, predominantly in big cities. The concentration of CO_2 is also high indoors, particularly in schools (Urbane et al., 2004a, 2004b; Wargocki & Wyon, 2013; Vilcane et al., 2015). The dust atoms adsorb on their surface different chemical constituents from the nearby air that also could have an effect on people's health and be the cause of other environmental complications. There are other sources from where the carbon dioxide could be formed indoors, like heating with firewood.

Chemicals that can cause hearing damage and balance troubles when inhaled, swallowed or absorbed through the skin – are found in certain pesticides, solvents and drugs, and the risk of their negative effects progresses when the workers are exposed to elevated noise levels (Sliwincka-Kowalska et al., 2003; Particle…, 2013). OSHA records that one precise kind of hearing loss – speech discrimination dysfunction – is particularly hazardous because the affected worker cannot separate co-workers' voices or notice signals from ambient noise. The research on ototoxicants and their interactions with noise is limited (Air…, 2015).

Do people really percept the risk of the increase of carbon dioxide concentration in the air and noise influence on health? Does the risk perception really exist? (Rundmo & Nordfjaern, 2017). The risk perception and validation have been studied regarding the city transport in Norway. The results do not support the idea that the risk perception could be hypothesized as a thoughtful concept of accident probability assessment and decision of the severity of the consequences. On the basis of the investigated literature, the risk perception related to the noise and air pollution consequences on health has not been studied profoundly.

The aim of the paper is to investigate the co-influence of noise and carbon dioxide on people in different situations (inside/outside houses/classrooms) depending of the traffic intensity, the fuel used for heating in residential buildings, etc.).

Five hypotheses have been formulated and the area to prove them concerning residents in the investigated panel house ($N = 71$; $N_{\leq 50} = 25$ persons; $N_{>50} = 46$ persons):

H1. It is hard to concentrate in noisy surroundings.

H2. I get mad when I hear loud music.

H3. I am easily awakened by noise.

H4. I often experience headaches due to noise in my apartment.

H5. I feel the air is not clean. The air in the living-room is stuffy.

The opinions of two groups of people have been compared.

MATERIALS AND METHODS

For measurements of carbon dioxide, the following standard methods have been used: EVS-EN-ISO 7726:2003 'Ergonomics of the thermal environments - Instruments for measuring physical quantities'. The measuring equipment used – TESTO 435. TESTO 435 allows to measure the concentration of CO_2 (0 ppm – 10,000 ppm).

For measurements of noise acoustics, the noise metre TES 1358 (type 1) with the range of 30–130 dB (A) has been used. The methods are presented in ISO 9612: 'System – Guidelines for the measurement and assessment of exposure to noise in a working environment' and ISO 1996-2: 'Acoustics – Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels'.

The noise measurements have been carried out in Riga and Tallinn, as well as in rural areas of Estonia and Latvia, during autumn of 2019. The measured points are presented in Table 1. The air pollutant is carbon dioxide. The noise and carbon dioxide levels have been measured outside and inside the houses. In Riga, the measurements have been carried out in the centre on the city.

Table 1. The results of measurements of noise (dBA) and carbon dioxide (CO_2)

Object	Noise level *± 1 dB	CO_2 level **± 10 ppm	Notes
Apartments in Tallinn			
1) rooms facing a motor road	30.0–33.0*; with opened window: ≤ 60 dB(A)	628**	Impossible to sleep with an opened window
2) rooms facing the courtyard	30.4–31.1	622	
3) environmental data	74–79 (45 cars pass by in a minute)[1]	503	Busy traffic at 6:30 pm
Houses in the rural area in the south of Estonia[2]			
1) houses in the rural area in the south of Estonia[2]	29.0–30.0	1,308	Heating by firewood
2) environmental data around the houses	30.0–31.0	326	Houses in the forest (Figs 6, 7)
Houses on the island Muhu in the west of Estonia[3]			
1) inside the houses	29.0–30.0 Especially from tractors 65 dB(A)	840–900–1,257	Heating by firewood; temperature: 24.4 °C; humidity: 34%
2) environmental data near the houses	29.0–30.0	450–480–543	
Hotel near the Daugava River, Riga, Latvia			Heavy traffic, 17.00 (Figs 3, 4)
1) inside a hotel	35.0–55.0 (opened window)	535	
2) outside in front of the hotel	70.–79.0	487	Heavy traffic
Schools in Latvia			
1) inside the classrooms	35.0–40.0	1,500–2,000	
2) outside	70–79.0 in the capital; 0–60 in the suburbs	513–850	Depending on the season. In summer, the concentration is higher.
In a small car (Skoda-Fabia)			
1) inside the car	Noise from wheels and music: 45.0–55.0	1,348	Temperature inside 18 °C; humidity 51%
2) outside the car	65.0–66.0	487	

* Uncertainty of measurements; [1] The number of driving cars (mainly private cars) has been counted, uring 5 minutes (N = 225); [2] Isolated houses in the forest; [3] Russian-type village houses (10, very near).

An interview method has been used to assess the annoyance caused by noise and impurities of the air (CO_2) inside the residential building (Fig. 3) and in twenty schools in Latvia. The main type of noise is traffic noise.

In Estonia, the residential buildings have been selected in Tallinn and in rural areas such as the Muhu Island and Otepää in the south of Estonia (Fig. 1). The noise and CO_2 levels have been measured inside and outside the buildings. In Tallinn, the inhabitants of a residential panel type building (Fig. 2) have been asked to fulfil a questionnaire. Ninety questionnaires have been provided, the response rate being 79. Windows of the apartments (of the panel building in Tallinn) face a busy street or a courtyard.

In the qualitative study, the respondents were asked separate questions about annoyance caused by each source of noise, such as: 'How much annoyance do you feel about the individual indoor and outdoor noises?' 'How would you describe your sensitivity to noise?' The reactions to noise in specific situations have been investigated through the questionnaire.

The Weinstein's scale has been used for investigation of sensitivity to noise (Ryu & Jeon, 2011):

1. I cannot concentrate well in noisy surroundings (Int+Ext)*
2. I complain once I am out of patience due to a noise (Int+Ext)
3. I often desire a quiet environment (Int+Ext)
4. I am annoyed even by low noise levels (Int)
5. There are often times when I want complete silence (Int+Ext)
6. I get mad when I hear loud music (Int)
7. Noise disturbs my concentration when reading a newspaper (Int)
8. I cannot fall asleep easily because of the noise (Int+Ext)
9. I find it hard to relax in a noisy place (Int+Ext)
10. I would not like to live on a noisy street, even if the house/apartment were nice (Ext)
11. I would not like to live across the street from a fire station (Ext)
12. I would not like to live in a house with poor noise insulation (Ext)
13. I am easily awakened by noise (Int)
14. I am confused by noise (Int)
15. Noise during a meal makes me uncomfortable (Int)
16. I feel uneasy when I hear noise (Int)
17. I often experience headaches and/or digestive disorders due to noise (Int)
18. I feel that the air in the room is not clean (Int).

** Int- internal*

Ext- external.

The last question to find out about the influence of the high carbon dioxide levels has been added to the Weinstein original questionnaire. To evaluate the annoyance of noise and CO_2, the survey has used a seven-point verbal scale comprised of the following responses: not at all, insignificantly, somewhat, moderately, considerably, highly and extremely. The respondents from the panel-house apartments rated their annoyance and sensitivity to noise. Among the respondents, 55% are from the age group 20–60 years, 20% are retired persons (mean age 76) and 25% are children: Replies of the residents have been divided into two groups: $>$ 50 years old (46 filled forms) and $\leq$ 50 years old (25 filled forms).

A one-way analysis of variance (ANOVA) has been conducted by using sensitivity scores of each group of indoor and outdoor noises, including carbon dioxide levels).

Figure 1. A private house near the Est-Lat border.

Figure 2. The investigated residential house is on the on the right (behind the trees).

Figure 3. The measurement of environmental noise in Riga.

Figure 4. Noise and CO_2 investigations in Riga (hotel).

Theory

The investigations on the co-influence of noise and carbon dioxide on the humans are limited (Sliwinska-Kowalska et al., 2003), but the importance for such investigations are certainly needed due to the increase of the carbon dioxide level in towns and the growing intensity of road transport, particularly in summer.

Millions of workers are wide-opened to noise in the workrooms each day and when uncontrolled, noise exposure may cause an everlasting hearing damage. Investigations show exposure to definite chemicals, called ototoxicants, which may cause hearing loss or stability problems, irrespective of the noise exposure. Substances including certain pesticides, solvents and drugs that contain ototoxicants can undesirably affect the ear, causing hearing loss, and/or affecting the balance (Fig. 4).

Another worldwide exposure is tobacco, consumed by approximately 1.3 billion of the global population (Shafey et al., 2003; Ferrite & Santana, 2005). Tobacco may also affect cochlear blood supply, because it causes peripheral vascular changes, such as increased blood viscosity and reduced available oxygen.

It is widely recognised that exposure to air smog can lead to a wide variety of opposing health effects (Brunekreef & Holgate, 2002). Air pollution is, for example, causing the increased risks of respiratory (Gehring et al., 2013) and cardiac diseases (ESCAPE, 2007. Exposure to ambient air contamination has also been suggested to increase the depression signs; however, few epidemiological studies have examined these special effects. Exposure to ambient air pollution may be related to the weakened mental health, including depression (Zijlema et al., 2016). Four European general population cohorts have found no consistent evidence for a link between the ambient air pollution (consisting of $PM_{2.5}$, PM_{10} & nitrogen dioxide) and the depressed attitude.

The Nordic Expert Group (Johnson & Morata, 2010) published a comprehensive review of occupational exposure to chemicals and hearing loss, summarising the writings on this topic from 1950 to November 2007. The chemicals were chosen based on the widespread indication on their ototoxicity. The review includes medications, organic solvents, metals, pesticide, and polychlorinated biphenyls. Contacts near or below the present occupational exposure limits (OEL) have resulted in hearing deficiencies for the following chemicals: styrene, toluene, carbon disulphide, lead, mercury and carbon monoxide. Another assessment of the effects of ototoxic substances on animals and humans was conducted in 2009 and the results showed that ‘lead, styrene, toluene and trichloroethylene are ototoxic and ethyl benzene, n-hexane and p-xylene are possibly ototoxic at concentrations that are related to the occupational location’. The authors also note that carbon monoxide possibly interrelates and toluene does interact with noise exposure to worsen hearing loss.

Workers are regularly exposed to numerous features and substances that are hazardous to health (Fig. 5), (Campo et al., 2013; Traumann, 2014). In 2005, about 30% of the European workers recounted being exposed to noise during at least a quarter of the time spent in their work environment (Parent-Thirion et al., 2007). Even though occupational noise exposure has long been documented in the US and Europe as the most damaging factor to hearing, the impact of chemical-induced hearing loss on workers should not be undervalued (Morata, 2003).

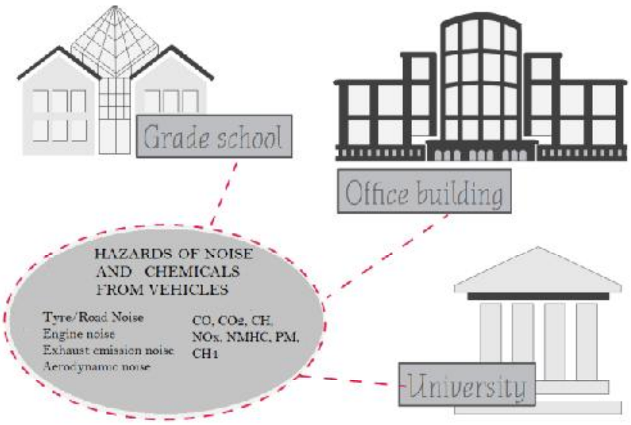

Figure 5. The noise and carbon dioxide pollution (Traumann, 2014).

Harmful exposure to ototoxicants (Fischer et al., 2015; Exposure…, 2018) may happen through breath, eating, or skin absorption. Health effects caused by ototoxic chemicals differ grounded on exposure occurrence, strength, length, workstation exposure to other hazards, and individual factors such as oldness. Properties may be transient or everlasting, can affect hearing compassion and result in a standard threshold shift. As chemicals can affect central portions of the auditory system (nerves in the central nervous system, the routes to the brain), not only do noises need to be louder to be identified, but also they lose clarity. The risk of workplace injuries increase due to the incapacity to hear co-workers, environmental sounds and cautionary signals (Job, 1988).

Industrial ototoxic chemicals have been assessed predominantly through animal studies (Campo et al., 2013). Bergström & Nyström (1986) published the results of the study of hearing quality of 319 Swedish employees. The study reveals that 23% of the workers who were also in contact with chemicals, suffer from hearing impairment. In the studies of Fechter et al. (2004), acrylonitrile was directed internally to rats in a high dose of 50 mg kg^{-1} d^{-1} for 1–5 days. Acrylonitrile potentiates everlasting noise-induced hearing loss particularly for high-frequency tones and particularly when acrylonitrile and noise are issued repetitively. The outside hair cells (OHCs) are the main objective of toxicity.

Environmental noise is recognised as a key health problem. The challenging health effects (general irritation, speech interference and sleep disorders) of transportation noise are well documented (Guidelines…, 2000). Unlike many other environmental problems, noise pollution is still worsening. In Sweden (Öhrström et al., 2006a, 2006b), the number of persons exposed to traffic noise exceeding the outdoor guidelines ($L_{Aeq.24h}$ = 55 dB and L_{Amax} = 70 dB) is approximately 2 million or 25% of the population.

People are exposed to noise inside their own homes and from neighbouring houses daily. The noises in residential buildings are numerous, including such things as floor impact sounds, airborne sounds like music and drainage noises from neighbouring units, as well as traffic noises from outside. In addition, ventilation systems and home appliances like refrigerators emit constant, steady noises. Noise in the living environment is an important factor in residential satisfaction (Sliwinska-Kowalska et al., 2003; Nijland et al., 2007; Preventing…, 2018).

RESULTS

The objects for measurements were as follows:

a) Apartments in a smoke-free panel house in Tallinn (Fig. 2), 20 m from a busy street, a bedroom facing the driveway or the courtyard. The questionnaire was completed by 71 residents of the panel house (Fig. 2);
b) House in the countryside (Fig. 1) in the south of Estonia, near the Latvian border;
c) House(s) on the island (Muhu) in the west of Estonia (countryside);
d) Hotel and outdoors near the hotel in the centre of Riga, near the Daugava River;
e) Schools in Latvia;
f) Inside a small car (Skoda-Fabia).

Carbon dioxide and noise have been measured at all of the measurement objects. The results are provided in Table 1.

Road transport is not the only source of constant noise in Riga. There is also railway, which noise level must be regulated in accordance with the EU Directives. In 2019, the number of complaints from residents of Riga in connection with large-scale road works increased. The highest noise levels in Riga are observed in the morning and evening hours, due to the traffic flow. According to Riga Department of Housing and

Environment, 120,000 people live in areas of acoustic discomfort, due to the noise from roads, the airport, industrial activity in the urban environment (Öhrström et al., 2006a, 2006b; Nijland et al., 2007; NZTA, 2014). Noise above 60 dB can cause cardiovascular diseases and nervous system disorders.

Investigation of air impurity and noise in isolated houses in South Estonia

Six isolated houses have been investigated. The results of the carbon dioxide and noise measurements inside the houses are as follows: 1) the elderly home: 873–1,322 ppm; noise: 40.1 dB(A); 2) the private houses: 1,098–1,316 ppm (firewood heating); 521–564 (distance heating) (Figs 6, 7). Outside the houses, the carbon dioxide concentration was from 320–353. The mean data are presented on the figures below. The noise levels differed - in the country area: 35.1 dB(A); in a small town near the investigated private houses - 350 ppm and the noise 65.2 dB (A).

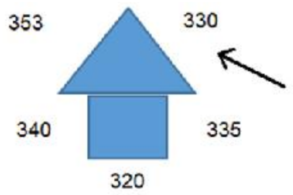

Figure 6. Elderly home, outside CO_2 (ppm).

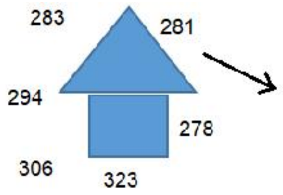

Figure 7. Private house, outside CO_2 (ppm).

Survey of the opinions regarding noise and CO_2 disturbance in residential houses

A reliability analysis has been conducted to ensure the internal consistency of the sensitivity questionnaire. The Cronbach's alpha (α) was *0.93*, indicating that the 18–item questionnaire had high internal consistency. The *p*-value was < 0.001.

The results (Table 2, Fig. 8) show that the inside noise is bothering people mostly on weekends. The inhabitants are mostly disturbed by the traffic noise at night. The investigation was carried out in autumn, but the people told that the noise was more disturbing in summer when windows need to be open as the outside temperature of the air is high and it is difficult to breath. The residents are highly disturbed by the noise when reading newspapers, they cannot fall asleep easily because of noise, and they do not want to live in the house with a poor noise insulation.

Table 2. Results of the noise sensitivity survey (Weinstein's questionnaire)

Question number		7-point scale						
1	2	3	4	5	6	7	8	9
4.6 ± 0.6	2.1 ± 1.6	4.7 ± 1.3	2.4 ± 1.5	3.5 ± 1.5	5.6 ± 1.7	5.9 ± 0.1	5.8 ± 1.2	6.9 ± 0.9
Score, SD								
Question number								
10	11	12	13	14	15	16	17	18
5.2 ± 0.8	6.5 ± 0.5	6.8 ± 0.8	5.2 ± 0.7	5.3 ± 0.7	5.4 ± 0.6	5.8 ± 1.2	4.0 ± 1.4	5.4 ± 0.6

Score, SD

The investigated house was renovated in 2016 (the inside walls were covered with heat- and soundproof material). Carbon dioxide was not very disturbing in autumn. The answer was mostly ‘considerably annoying’.

The questions 2, 4, 5, 17 have low numbers (unsatisfied) as they were assessed as disturbing factors by the older group of residents (age > 50 years). The younger people are more used to listening to music at lunch or reading newspapers.

The two groups of residents (> 50 years (I); ≤ 50 years (II) old) have been compared.

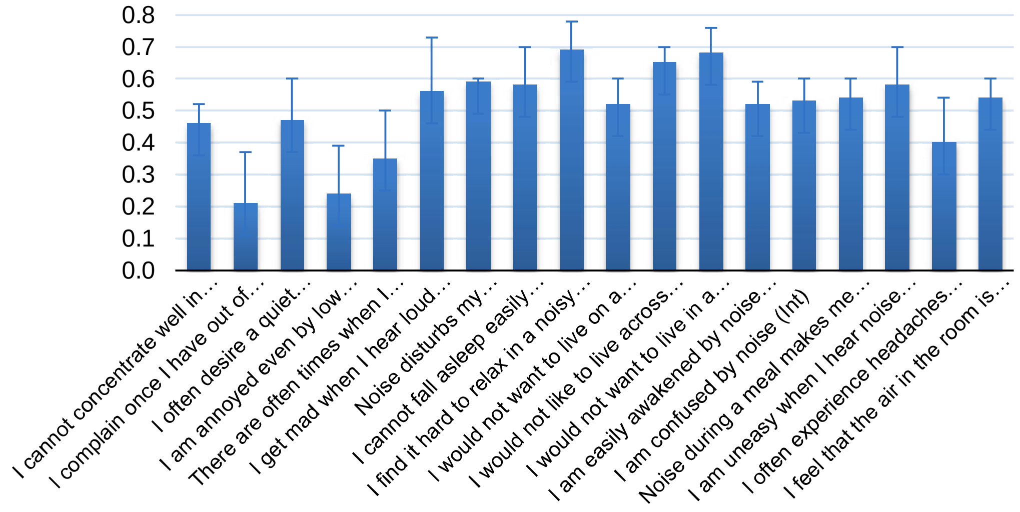

Figure 8 Results of the noise sensitivity survey according Weinstein’s scale.

Analysis of hypothesis

The hypothesis was proposed to find out about the influence of noise and carbon dioxide on people’s health in panel-type apartments (Table 3).

Table 3. Statistical analysis of the main hypothesis

Hypothesis and results	Categories	M	SD	*t-value*
H1 It is impossible to concentrate well in noisy surroundings. **Confirmed**	Noise and health	5.1 (I) 4.5 (II)	0.6	*1.695*
H2 I get mad when I hear loud music. **Not confirmed**	Noise and health	6.2 (I) 4.5 (II)	1.7	*0.18*
H3 I am easily awakened by noise. **Confirmed**	Noise and health	5.3 (I) 5.1 (II)	0.7	*1.02*
H4 I often experience headaches due to noise in my apartment. **Not confirmed**	Noise and health	5.2 (I) 3.8 (II)	1.4	*0.23*
H5 I feel the air not clean. The air in the living room is stuffy. **Confirmed**	CO_2 and health	5.4	0.6	*13.40*

The young people (≤ 50 of age) are not so sensitive to noise, but they are sensitive to carbon dioxide.

DISCUSSION AND CONCLUSIONS

The results of the current investigation have indicated that noise and carbon dioxide levels are high in big cities and as Riga is bigger that Tallinn and has more transport (also a railway), the investigated values are higher in Riga, Latvia. The main part of the investigation includes the study of influence of noise on people living in residential buildings near a driveway. It shows that the outside noise disturbs the inhabitants as much as the inside noise created by their neighbours, particularly at weekends.

The results of the Ryu & Jeon (2011) survey specify that the most frequently mentioned indoor noise sources are children jumping and running (67%), i.e. the floor impact noise, and playing musical instruments and people talking, i.e. the airborne noise. The road traffic noise (7%) is the most frequently mentioned outdoor noise (Ryu & Jeon, 2011).

Road noises are not mentioned as a disturbing factor in the Ryu & Jeon (2011) study. In the current study, the road noise is the main disturbing factor. The difference between the two investigations can be explained by different inhabitants in the houses. The panel building in Tallinn (built in the 1960s) is mostly populated by retired people, the proportion of little children is 5.0. All indoor noise sources were recorded at night in the rooms of two apartments with a low background noise level of 25 dBA.

Blocks of flats in Estonia and Latvia have noise-dumping qualities. Tight double windows give higher carbon dioxide levels.

Ryu & Jeon (2011): complaints regarding noises in living environments, including building noises and noises from household electric appliances, are increasing rapidly. The influence of sensitivity on annoyance was greater for indoor noise than for outdoor noise. In addition, different approaches toward indoor and outdoor noises may explain the result of the present study. Outdoor noises initiate from various undetermined sources people are less able to cope with. The correlation coefficients ($r = 0.29–0.39$) for annoyance between noises are lower than those ($R = 0.48–0.59$) between various indoor noise sources. The annoyance from indoor noises is greater than outdoor noises. Nijland et al. (2007) found that noises (mainly traffic noises) in residential locations influence the level of satisfaction with the living environment, and noise-sensitive people consider moving out more often. This indicates that a lower noise exposure in a residential space might be an important factor when deciding whether to obtain a house or to move out. The possibilities for moving out (changing the place of living, apartment) depends on the standard of living in the particular country and also on the age of people who would like to move out. In poor countries, it is not very easy to move out, as it funds are needed. Another problem is the age of inhabitants: older people are not able to move out any more.

The decrease of noise and carbon dioxide levels help people staying healthy and the environmental impact from the investigation is focusing the attention on the necessity and possibilities to decrease the concentration of CO_2 in the ambient air.

The future research can be carried out in hot environments and in summer time, when the noise and CO_2 levels in towns and in apartments are higher. It does not concern schools as they have holidays in summer.

Increasingly more investigations of air impurities and the quality of ventilation inside living and working premises are appearing, considering a new type of very dangerous hazards (Corona, Ebola, SARS) for the human health.

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