The Effect of Wooden Building Materials on the Indoor Air Quality of Houses

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Abstract. This work focuses on researching wood as a low-emitting building material. Many studies showed that by regulating the emission of adverse chemicals from pressed wood products, they could be recycled as low-emitting materials. The presented case study, shows the measurements of the indoor air quality in a passive, low-energy, wooden, light frame house. Concentrations of Volatile Organic Compounds (VOC) and formaldehyde were measured and compared with data from other case studies made in this subject and with the current Hungarian and international regulations of adverse chemicals. The main VOC materials which concentrations were significant in all measurements were terpenes (limonene, alpha-pinene, 3-carene), aliphatic-hydrocarbons and aldehydes (acetic acid, 2-Methoxy-1-ethylmethyl acetate). The comparison showed that the concentrations of benzene, toluene, naphthalene, formaldehyde, and styrene were not deviant from the average values measured by other case studies. The observations showed that the main influencing factors of indoor air quality were the changes in indoor temperature, relative humidity, air exchange rate, and human activities. The conclusion is that the wooden materials applied in the house are low-emitting materials and do not pose a health risk for people.

1 Introduction

The global climate change and increasing energy requirements have led to the development of airtight, energy-saving buildings with very low air exchange rates. Because of the cheap mass-production the most common building materials are synthetic materials. The houses may become more and more comfortable and automatized, still the question arises: Do these technical improvements provide a healthy living-space for people?

We spend 80-90% of our lives inside buildings [1]. Environmental health researchers have been investigating intensively the indoor air quality of newly built homes, existing homes and converted homes [2] [3] [4]. The guidelines of WHO (World Health Organisation) categorize the harmful substances emitted by the sources [5]. In Germany the Committee for the Health Assessment of Building Materials first defined VOCs from the emission of building products in 2000. Now more than 180 different VOCs can be defined [6]. There are some countries where the regulations of the indoor air quality define the building materials and the concentrations of adverse chemicals emitted from them. In the European Directive

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emphasized, that the buildings cannot pose a health risk to the residents through the emitted adverse chemicals [7].

With the right choice of building materials and technologies the sources of adverse chemicals can be avoided. Wood is one of the most environment-friendly raw materials [8] [11]. Wood cells contain high amount of carbon absorbed from the CO2 component of the air. Engineered wood products contain chemical materials in form of added adhesives or as surface treatment etc. These chemicals have significant emissions of volatile organic compounds (VOCs) that could cause health risk especially in indoor spaces [9] [10].

There are approaches made to develop ecological technologies in manufacturing and treatment of wooden materials [12-16]. There are several studies about the emission of VOCs and formaldehyde from wood-based composites, such as MDF, plywood, particleboards, etc. Ze-Li showed in their study that the most emitted VOCs were terpenes, aldehydes, and aromatics. Pine wood plank had the highest VOCs (approximately 900 µg/m3). Fresh particleboard showed the second highest value with 450 µg/m3 [17]. Another study compared the emissions of VOCs from air-dried pine wood and heat-treated pine wood. Significant chemical changes have occurred, and volatile monoterpenes and other low molecular weight compounds have evaporated from the wood during the heat-treatment process when compared to air dried wood [18]. The emission of wood-based materials depends on the type of wood. Hard wood emits high concentrations of acetic acid and formic acid, while soft wood emits more terpenes (alpha-pinene, 3-carene, etc.) [19].

Song-Yung measured the emissions of particleboard from recycled wood-waste chips using polymeric 4,4-methylenediphenyl isocyanate (PMDI) and phenol-formaldehyde (PF) resins. PMDI is one of the most used aromatic isocyanates in the world. 5 million of tones of PMDI are produced yearly. It doesn't pose a health risk, but it can cause irritation [20].

In other studies, there were used natural resins instead of UF or PF at the manufacturing of engineered wood. Sumin Kim used natural tannin as adhesive in wood-based flooring. They had to add PVAc to increase the bonding strength of tannin. The formaldehyde emission was lowered even by adding PVAc (Polyvinyl acetate), and more greatly reduced when UV curable urethane acrylate was coated [21]. The volcanic pozzoloan is another material added as scavenger to engineered wood, which reduced the emissions of formaldehyde [22]. In a newly-built wooden house the concentrations of the emitted adverse chemicals can be reduced with the "bake out" process. The inside temperature is raised to 32-40°C and kept it for a week. The extent of the reduction of adverse chemicals in the indoor air is about 60-90% [23].

There are lots of examinations made in test chambers measuring the emission of chemicals from the single building products. But still there are less study showing measurements of adverse chemicals in the indoor air of wood buildings [24].

The presented case study shows the measurements of the indoor air quality in a passive, low-energy, wooden, light frame house. Concentrations of Volatile Organic Compounds (VOC) and formaldehyde were measured and compared with data from other case studies made in this subject and with the current international regulations of adverse chemicals.

2 Measurement

The sampling was performed in a newly built, low-energy, frame-house. Description sees in our former paper [25]. Six measurements were taken in different phase of building process throughout the period of a year. The results of the measurements showed the changing concentrations of adverse chemicals (Table 1).

Table 1. Comparison of the measured values with the mean values related to Middle-European case-studies.

Measure-ments	1.	2.	3.	4.	5.	6.	Mean value Middle Europe
	(μg/m³)						
Benzene	3.11	2.79	0	1.66	2.35	1.65	3.1
Toluol	11.6	5.09	6.13	19.07	38.4	4.81	20.6
Styrol	3.06	1.32	0	4.98	147	7.93	1.1
Formaldehyde	34	11	130	49	99	32	29.8
Naphtalene	0	0	0	1.81	1.15	0	1.1
Limonene	64.7	21	15.8	59.7	289	30.2	17.2
Alpha-pinene	297	170	300	300	2710	284	12.9

By summing the measured concentrations of VOCs, we get the TVOC values. These values are plotted in Fig.1. The graph clearly shows that TVOC concentrations were influenced by indoor temperature, indoor relative humidity, and air exchange rate. Human activities and the furniture had the greatest impacts on the concentrations. The TVOC value of the first measurements was 2150 µg/m3, the last was 1190 µg/m3. After the first measurement the air-heating was turned on, and the indoor temperature was not increased, this is the reason of the decreasing values. Before the 4. measurement the floor-heating was turned on, the indoor temperature lifted to 21°C. This must have caused the increased concentrations. This assumption of ours seems to be confirmed by study of Young [28]. During June the indoor temperature raised above 24°C which indicated the significant change in the concentrations. In this period were the rooms furnished, which could have affected the increasing values as well. Probably the frequent natural ventilation indicated the lowering of high VOCs concentrations.

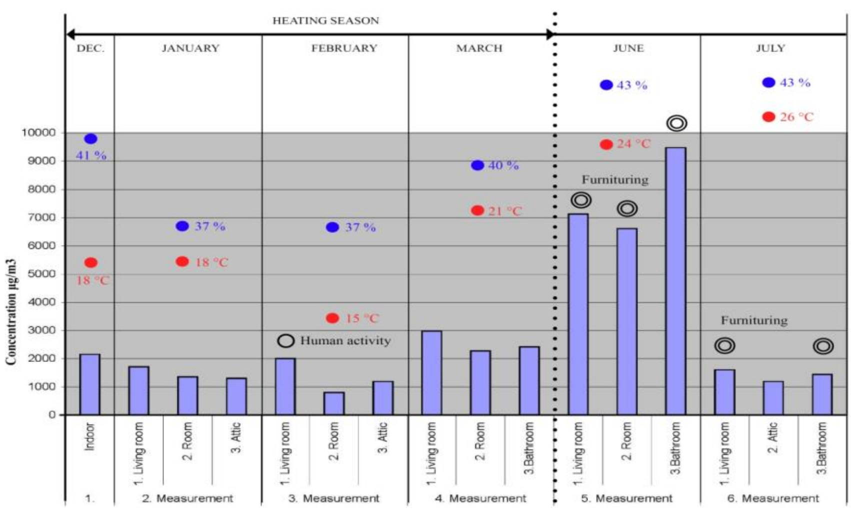

Fig. 1. TVOC values of the measurements. The red dots show the indoor temperature, the blue dots show the indoor relative humidity.

The concentrations of benzene (3.5 μg/m3) were not deviant from the average values measured in other case studies, and from the current Hungarian and international regulations of adverse chemicals (Fig. 2). They did not pose a health risk. The concentration of toluol was between 2.9 – 38.4 μg/m3. The increase was affected by indoor temperature, indoor relative humidity, and the presence of furniture in the room. The highest concentration exceeded the maximal value given by WHO (20 μg/m3).

The concentration of formaldehyde with the value of 130 μg/m3 did overpass the values of the current international regulations by the WHO (100 μg/m3) during the third measurement, but it was just temporary (Fig. 3). The main sources were the wooden materials cut into pieces in the living room. By the following measurements the concentration of formaldehyde was slightly increased because of the rise of the indoor temperature.

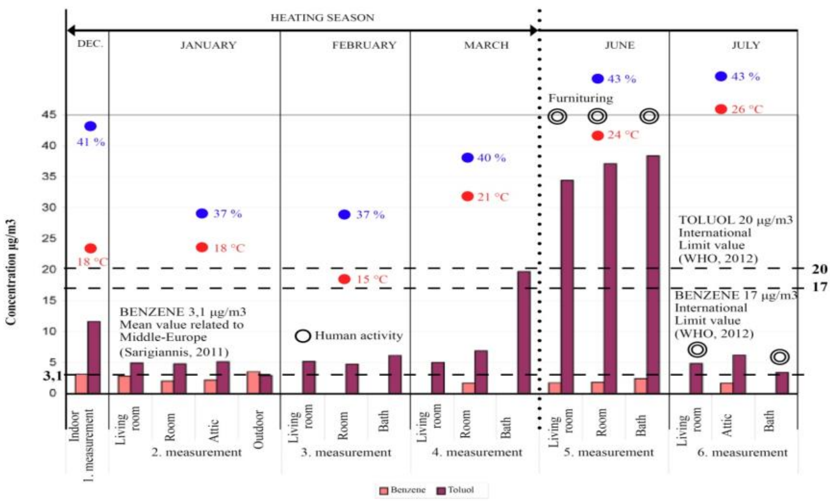

Fig. 2. Benzene and toluol values of the measurements. The red dots show the indoor temperatures, the blue dots show the indoor relative humidity.

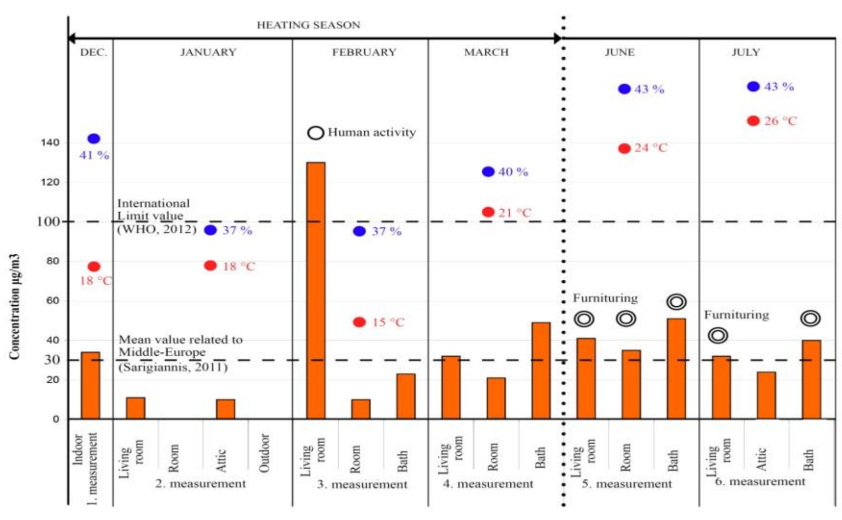

Fig. 3. Formaldehyde values of the measurements. The red dots show the indoor temperatures, the blue dots show the indoor relative humidity.

The rate of the wooden clothing in each room had a great influence on the concentrations of alpha-pinene and 3-carene. These chemicals are not toxic, therefore they did not pose a health risk. Fig.4. shows the influence of indoor temperature, indoor relative humidity, and the presence of furniture in the rooms on the concentrations.

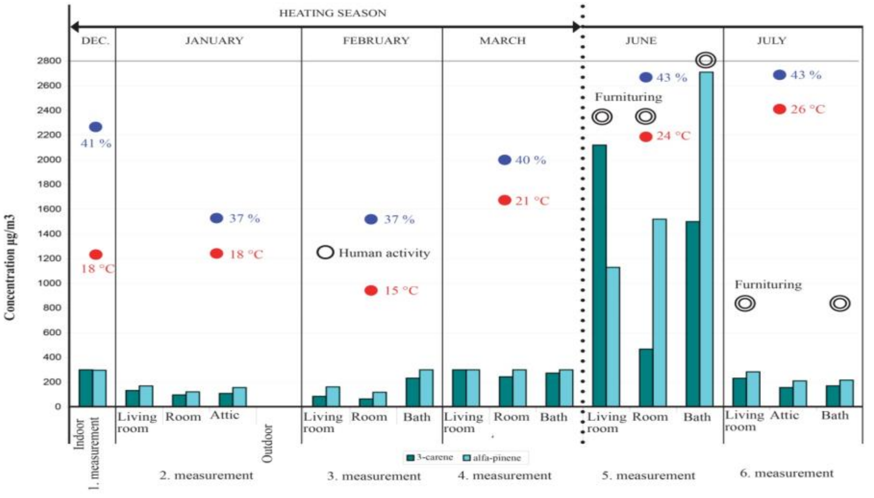

Fig. 4. 3-carene and alpha-pinene values of the measurements. The red dots show the indoor temperatures, the blue dots show the indoor relative humidity.

3 Comparison with other studies

During literature survey we have found around 200 papers regarding in-situ measurements of IAQ in buildings, reviews and chamber test methods of building materials. After sampling the measurement data we compared some of them with our values. But it still shows a very chaotic picture about the guidelines of measurements, which makes it hard to evaluate them. Each country has different regulations of maximal exposures of adverse chemicals and different measuring methods as well.

For a detailed analysis a further research work is needed.

The case studies were categorized into three main groups:

- Conventional, newly-built or renovated houses (before moving in and after moving in)
- Conventionally-built houses
- Houses with low-emitting building materials (before moving in and after moving in)

The strategy of the comparison was based on the maximal and minimal TVOC values measured in our study. In Table 2 are the chemicals chosen to be compared.

3.1 Conventionally built and renovated houses

Rothweiler measured in their study the IAQ of newly-built or renovated apartments. Their results showed an elevated percentage of aldehydes, ketons, and alcohols. They suspected that the high concentrations and the lack of ventilation can cause - immediately after moving - in symptoms of head-ache, irritation of the eyes. The presence of furniture and human activity cause an additional rise of the concentrations table 2 [26].

Seung H. examined the indoor air quality of 107 newly-built apartments in Korea at the pre-occupancy stage. The dominant VOCs were: formaldehyde, aromatic hydrocarbons, alcohols, terpenes, and ketons. The high concentration of formaldehyde could be caused by not following the Korean Ministry of Environment guidelines for formaldehyde emissions. The main sources were suspected to be wood panels, vinyl floor coverings, adhesives and paints table 2 [27].

The conclusion is that our measured values are mostly the lowest, with the exception of limonene. That is the effect of the high percentage of the wooden materials in the house.

3.2 Conventionally built houses

Kostiainen quantified 48 compounds on the basis of their prevalence, toxicity, carcinogenicity and mutagenicity in 50 normal houses. They have measured high concentrations of VOCs in normal houses, which suspected, that not only VOCs are affecting the indoor air quality [29].

Tuomainen measured the indoor air quality of normal houses, and found that the concentration of TVOC were significantly higher before the residents moved in because of the deficient ventilation and the high-emitting building materials [30].

Compared to these two case studies the minimal values from our measurements were lower, but the maximal values were significantly higher (Table 2).

Table 2. Comparison of values of VOCs and TVOC measured in conventionally built houses with values from relevant case studies found in the literature.

Components	Measure values Patkó et al. (2013)		Case studies from literature			
			KOSTIAINEN (1995)		Tuomainen et al. (2000)	
	Min. value	Max. value	Min. value	Max. value	Before moving in	After 5 months
Benzene	1.65	3.11	0.21	38.55	-	-
Toluol	4.81	38.4	0.6	70.36	-	84
Styrol	1.32	147	0.08	3.87	-	-
Formaldehyde	11	130	-	-	12.0-27.0	5.0-19.0
Naphtalene	1.15	1.81	0	1.63	-	-
Limonene	15.8	289	1.34	51.56	-	19
Alpha-pinene	170	300	1.05	36.41	-	51
TVOC	**795**	**7130**	**40.84**	**235.85**	**1290.0-9580.0**	**170.0-1335.0**

3.3 Houses with low emitting building materials

Tuomainen investigated the IAQ of houses built by following the instructions of the Finnish Classification of Indoor Climate, Construction and Finishing Materials. The ventilation system was kept at a high capacity for one week after its completion before occupants moved in. Indoor air parameters were measured in one apartment on each floor before occupants moved in (2 measurements) and after a 5-month occupancy [30].

In the study of Guo a low volatile organic compound (VOCs) emission house was investigated. The construction materials used in the house were tested in an environmental chamber and low VOC emission materials were then selected. The ventilation was maximized by the right placement of the windows. The TVOCs concentrations measured in the house ranged from non-detectable to 43 (μg/m3). This study confirmed that for controlling IAQ was pollution prevention very effective and the next most important was the design of ventilation rates to handle uncontrollable sources [31].

The volatile organic compounds (VOCs), formaldehyde, and ammonia concentrations as well as temperature, relative humidity, and the air exchange rate were determined right after the finish and after 6 and 12 months. 240 VOCs were detected, from which xylol and alpha-pinene had the highest concentrations. After six months the values of TVOC were significantly decreasing. The concentrations of ammonia and formaldehyde showed seasonal variations, i.e., higher concentrations were measured in summer [32].

Compared to these two case studies the minimal values from our measurements were lower, but the maximal values were significantly higher (Table 2 and Table 3).

Table 3. Comparison of values of VOCs and TVOC measured in ecologically built houses with values from relevant case studies found in the literature.

	Rothweiler et al. (1992)	Seung H. et al. (2012)	Case studies from literature						
			Tuomainen et al. (2000)			Guo et al. (2003)	Jarnstrom et al. (2006)		
Components	Avg. value	Avg. value	Before aeration	After 1 week	After moving in	After 1 year	After finish	After 6 months	After 1 year
Benzene	20	3.9	-	-	-	-	0	0	3
Toluol	9741	184	-	19	12	-	-	-	-
Styrol	167	2.7	-	-	-	-	3	2	3
Formaldehyde	1200	62	1.0 - 20.0	6.00 - 15.00	2.00 - 21.0	-	19	21	26
Naphtalene	219	0.8	-	-	-	-	-	-	-
Limonene	224	4.3	-	140	23	-	12	10	12
Alpha-pinene	867	9	89	46	-	-	61	37	35
TVOC	**31696**	-	**210-1800**	**100 - 1100**	**61 - 410**	**0 - 43**	**780**	**329**	**247**

4 Conclusion

The comparison showed that the concentrations of benzene, toluene, naphthalene, formaldehyde and styrene were not deviant from the average values measured by other case studies. The observations showed that the main influencing factors of indoor air quality were the changes in indoor temperature, relative humidity, air exchange rate, and human activities. The conclusion is that the wooden materials applied in the house are low-emitting materials and do not pose a health risk for people.

The measurements of indoor air quality showed a great number of new information about the correlation of building materials, the use of the building, and indoor air quality. They are providing the designers and the building occupants with essential information about the state of the building and the health impacts. They can be used in many types of the architectural processes, e.g. in building diagnostics for renovations, in measuring the health impacts of a newly built house, and in finding the main sources of adverse chemicals of buildings with "sick building syndrome".

By choosing the right building materials (low-emitting materials) and technologies can these adverse impacts on the indoor air quality be avoided. For this, there must be a regulated and up-to-date database of low-emitting materials accessible for designers and building contractors, to create with breathing structures an environmentally conscious, healthy living-space. More in-situ measurements are needed, to get a wider view of the health state of buildings and how they affect our health.

References

1. WHO: *Guidelines for indoor air quality: selected pollutants*, Denmark: WHO Regional Office for Europe, ISBN 978 92 890 0213 4 (2010)
2. T. Salthammer, S. Mentese, R.Marutzky, *Formaldehyde in the indoor environment*. Chemical Reviews **110**, (pp. 2536 – 2572), (2010)
3. P. Wolkoff, *How to measure and evaluate volatile organic compound emissions from building products*. A perspective. Science of the Total Environment, **227**, (pp. 197–213.) (1999)
4. B. Holmberg, P. Lundberg, *Benzene: standards, occurrence, and exposure*. Am J Ind Med; **7**:375–83. (1985)
5. WHO. *Air quality guidelines, global update 2005, particulate matter, ozone, nitrogen dioxide and sulphur dioxide*, Denmark: WHO Regional Office for Europe, 2006, ISBN 92 890 2192 6 (2006)
6. AgBB, Updated List of LCI values 2012 in Part 3, Health-related Evaluation Procedure for Volatile Organic Compounds Emissions (VOC and SVOC) from Building Products, (2012)
7. A. Katsoyiannis, P. Leva, J. Barrero-Moreno, D. Kotzias, *Building materials. VOC emissions, diffusion behaviour and implications from their use*. Environmental Pollution **169** (pp. 230 – 234) (2012)
8. S. Molnár *Forest and Wood Utilization in Hungary, Erdő - fa hasznosítás Magyarországon*, NyME Erdészeti Tudományos Intézet, (p. 344) (2005)
9. H. Guo, F. Murraya, S.-C. Lee, *Emissions of total volatile organic compounds from pressed wood products in an environmental chamber.* Building and Environment **37**, (pp. 1117 – 1126) (2002)
10. EPA (Environmental Protection Agency) *Sources and factors affecting indoor emissions from engineered wood products: summary and evaluation of current literature.* EPA-600=R-96-067. North Carolina: Research Triangle Park, (1996)
11. A. Petersen, B. Solberg, *Environmental and economic impacts of substitution between wood products and alternative materials: a review of micro-level analyses from Norway and Sweden*. Forest Policy and Economics **7**, (pp. 249– 259) (2005)
12. P. Takáts *Formaldehyde content of wood-based composite boards; Faalapú kompozit lemezek formaldehid tartalma I*. Magyar Asztalos IV: **5** (pp. 48−49) (1994)
13. P. Takáts *Formaldehyde content of wood-based composite boards; Faalapú kompozit lemezek formaldehid tartalma. II.* Magyar Asztalos IV: **7**, (p. 47) (1994)
14. Takáts P. Emission threshold limits of composite panels; Kompozit lemezek emissziós határértékei. Magyar Asztalos IV: **9**, (p. 56) (1994)
15. P. Takats, A. Winkler, L. Albert, Zs. I. Nemeth *Formaldehyde Contents of Particleboard: Comparing WKI−Method and with FESYP Perforator Test Method*,

„5th International, Jubilee Conference on Role of Formaldehyde in biological systems, October 9−13. Sopron, Hungary, (pp. 54-58) (2000)

16. T. Alpár, R. Németh, P. Takats, *Renewable composites, materials, R+D+I on the Wood Science Faculty; Megújuló Kompozitok, anyagok, K+F+I a Faipari Mérnöki Karon,* Inno-Lignum.09.06-08. (2012)
17. Ze-Li, Q., Fei-Bin, W., Jian-Zhang, L., Takeshi, F. Assessment on emission of volatile organic compounds and formaldehyde from building materials. Composites: Part B **49**, 36–42 (2013)
18. A. Manninena, P. Pasanenb, J.K. Holopainen, *Comparing the VOC emissions between air-dried and heat-treated Scots pine wood*. Atmospheric Environment **36**, (pp. 1763–1768) (2002)
19. M. Risholm-Sundman, M. Lundgren, E. Vestin, P. Herder *Emission of acetic acid and other volatile organic compounds from different species of solid wood*, Holz als Roh und Werkst. **56**, (pp. 125–129) (1998)
20. W. Song-Yung, Y. Te-Hsin, L. Li-Ting, L. Cheng-Jung, T. Ming-Jer *Properties of low-formaldehyde-emission particleboard made from recycled wood-waste chips sprayed with PMDI/PF resin*, Building and Environment **42**, (pp. 2472–2479) (2007)
21. K. Sumin, *Environment-friendly adhesives for surface bonding of wood-based flooring using natural tannin to reduce formaldehyde and TVOC emission*, Bioresource Technology **100**, (pp. 744–748) (2009)
22. K. Sumin, *The reduction of indoor air pollutant from wood-based composite by adding pozzolan for building materials*, Construction and Building Materials **23**, (pp. 2319–2323) (2009)
23. K. Sumin, C. Yoon-Ki, P. Kyung-Won, K. Jeong Tai *Test methods and reduction of organic pollutant compound emissions from wood-based building and furniture materials*, Bioresource Technology **101**, (pp. 6562–6568) (2010)
24. C.J. Weschler, *Changes in indoor pollutants since the 1950s*, Atmospheric Environment **43**, (pp. 153–169) (2009)
25. Cs. Patkó, *Evaluation of volatile organic components of indoor air of a newly-built wooden frame house in the last four seasons*. Conference Proceedings Part (A) 4th INTERNATIONAL CONFERENCE “TO PROTECT OUR GLOBAL ENVIRONMENT FOR FUTURE GENERATIONS” ICEEE-, 20 – 21 November 2013, Óbuda University Budapest, Hungary, (pp. 229-237) ISBN: 978-615-5018-93-0 (2013)
26. H. Rothweiler, P. Wager, C. Schlatter, *VOLATILE ORGANIC COMPOUNDS AND SOME VERY VOLATILE ORGANIC COMPOUNDS IN NEW AND RECENTLY RENOVATED BUILDINGS IN SWITZERLAND*. Atmospheric Environment Vol 26A No **12**, (pp 2219-2225) (1992)
27. H. Seung, K. Wan, *Volatile organic compound concentrations, emission rates, and source apportionment in newly-built apartments at pre-occupancy stage*. Chemosphere **89** (pp. 569–578) (2012)
28. L. Young-Kyu, K. Hyun-Joong, *The effect of temperature on VOCs and carbonyl compounds emission from wooden flooring by thermal extractor test method*. Building and Environment **53**, (pp. 95 – 99) (2012)
29. R. Kostiainen, *Volatile organic compounds in the indoor air of normal and sick houses*. Atmospheric Environment, Vol. **29**, No. 6, (pp. 693-702) (1995)

30. M. Tuomainen, A-L. Pasanen, A. Tuomainen, J. Liesivouri, P. Juvonen, *Usefulness of the Finnish classification of indoor climate, construction and finishing materials: comparison of indoor climate between two new blocks of flats in Finland* Atmospheric Environment **35**, (pp. 305-313) (2001)
31. H. Guo, F. Murray, S.C. Lee, *The development of low volatile organic compound emission house—a case study*. Building and Environment **38**, (pp. 1413 – 1422) (2003)
32. H. Järnström, K.Saarela, P. Kalliokoski, A.-L. Pasanen, *Reference values for indoor air pollution concentrations in new residential buildings in Finland*. Atmos. Environ. **40**, (pp. 7178–7191) (2006)