Reference task Environment and Health - Indoor environment

March 2018

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An examination of whether the intervention value for formaldehyde in the indoor environmental decree was exceeded within six months of the use of sheet materials containing formaldehyde.

Carbonyls, especially formaldehyde, are ubiquitous in the indoor environment and have been associated with both chronic and acute health effects. The main sources of indoor formaldehyde include degradation of additives in wood-based building materials, furniture, and sealants as well as combustion and chemical reaction common to the indoor environment (Frey et al. 2015). Numerous studies have connected the increased indoor formaldehyde air concentration with the newly renovated and/or newly decorated indoor environments resulted by decreased ventilation rates and/or introducing additional sources of formaldehyde emissions (e.g. panel wood furniture, flooring materials).

Since the introduced in 2010 Energy Performance of Buildings Directive (EPBD) many European countries initiated several programmes for improving energy efficiency of the newly build as well as the existing buildings. The low-energy and passive house concepts have become more and more common during past couple of years regarding their economic advantages compared to conventional buildings, even when the higher investment costs were accounted for (Audenaert et al., 2008). However, measures to save energy in buildings are typically based on energy models, engineering judgment and cost-benefit analysis, rarely considering the potential effects on indoor air quality. Several studies have connected the commonly used approaches for increase the buildings' energy efficiency (e.g. tightening of building envelopes and decreased ventilation rates) to increased concentrations of indoor air pollutants and deteriorated indoor air quality. Moreover, using new building materials (e.g. insulation materials, flooring, decorations, furniture) have also additional contribution to the increased concentrations of indoor air pollutants (Fisk et al., 2009, Földváry et al. 2017, Broderick et al. 2017).

In order to answer the questions, listed above, a short literature review of the available studies recently published in the scientific literature has been performed. The review was mainly focused to the effect of various renovation and redecoration measures on the indoor formaldehyde concentrations in studies performed in Europe or North America. An overview of this literature review is shown in Table 1.

The overall outcomes of these studies show that in most of the investigated indoor environments, the formaldehyde air concentrations measured before and shortly after the renovations are below the newly proposed in *The Flemish Indoor Environment Decree* target and intervention limit values of 100 µg/m³. These results are in line with other European studies where similar median indoor formaldehyde concentration were reported in different buildings (with and without renovation interventions) in Sweden (12.3 µg/m³ (Bornehag, 2000) and 13 – 22 µg/m³ (Langer, 2013)), Finland (40.5 µg/m³ (Jurvelin et al., 2001)), England (24 µg/m³ (Raw et al, 2004)), France (16.3 µg/m³ (Blondel et al., 2011), 19.7 µg/m³ (Langer et al., 2016)) and Denmark (40 µg/m³ (Kolarik et al., 2012)). These formaldehyde concentrations measured in European indoor environments are relatively lower in comparison with these reported from studies performed in other countries such as China (median of 125 µg/m³ (Huang et al.,2017)), Turkey (range between 2.3 – 866.2 µg/m³ (Mentese et al., 2006)) and Hong Kong (median of 85.7 µg/m³ (Guo et al., 2009)) due to variety of regulations regarding emissions from formaldehyde containing building materials and furniture implemented in several European countries (Salthammer et al., 2010).

In term of the effect of the renovation onto the formaldehyde concentrations, most of the studies (presented in Table 1) reported up to 60% increase in the formaldehyde concentration shortly after performed renovation in comparison with the levels measured before the renovations. The authors associate these increased levels of formaldehyde with to the newly installed formaldehyde contain products in the environments after renovation as well to the reduced ventilation rates. However, in one of the buildings, in the study performed by Noris et al. (2013), the authors reported decrease of about 48% of the formaldehyde concentration measured in the apartments of that building shortly after renovation measures. The authors however explain the change in the formaldehyde concentration in that particular building by increased ventilation rates in the apartments due to installation of a new mechanical ventilation system. Moreover, such trend was not observed in the other two building investigated during this study. No other survey has showed higher formaldehyde concentration measured prior the renovation in comparison with the concentrations assessed after the renovation.

Table 1 Overview of recent scientific literature on energy-efficient renovations in relation to the concentration of formaldehyde in indoor environments

Author	Study	Formaldehyde concentration		Conclusion
		Pre renovation	Post renovation	
Földváry et al. 2017	The study evaluates the impact of energy renovation of multifamily residential buildings in Slovakia on indoor air quality, air exchange rate and occupant satisfaction. Three pairs of identical naturally ventilated buildings where exanimated before and after simple energy retrofitting. The energy retrofitting measures included thermal insulation of the façade and the roof, and hydraulic balancing of the continuously operating heating system.	15 – 54 $\mu g/m^3$ (median 30 $\mu g/m^3$)	23 – 67 $\mu g/m^3$ (median 42 $\mu g/m^3$)	The study reported increase about 60% of the indoor formaldehyde concentration after energy retrofitting. The increased formaldehyde concentrations were associated with newly installed insulation materials and decreased air exchange rate in indoor environments after renovation.
Broderick et al. 2017	Concentrations of indoor air pollutants in fifteen, three bed semi-detached co-operative social dwellings in Ireland were monitored before and after energy upgrade including wall and roof insulation, and ventilation upgrade.	15.43 ± 3.85 ppb (~18.95 $\mu g/m^3$)	24.27 ± 2.97 ppb (~29.81 $\mu g/m^3$)	An increase of 57% in the formaldehyde concentrations has been observed in the dwellings after energy retrofitting measures. The increased formaldehyde concentrations are associated with new furnishings and building materials used during the retrofit as well as the reduced air exchange rates.
Dodson et al. 2017	The study examine the impact of renovation on indoor pollutants levels in 37 newly renovated "green" low-income housing units in Boston before and after occupancy. The renovation of the units is focused mainly on energy	-	Pre occupation: 4.4 -27 $\mu g/m^3$ with median of 17 $\mu g/m^3$	The concentration of the formaldehyde showed steady levels before and after occupation. This observation

	efficiency, including high efficiency windows, additional insulation, energy star appliances, low energy lighting and low VOC paints. In addition the renovation also aimed to modernize the units by installing new flooring, baseboards and cabinets.		Post occupation: 1.5 -28 μg/m³ with median of 11 μg/m³	suggested that formaldehyde appeared to have both building and occupant sources.
Prasauskas et al. 2016	This study investigates the effects of energy retrofits on indoor air quality in three northern European countries. Indoor air pollutants were measured in 24 apartments in Finland, 10 apartments in Estonia, and 15 apartments in Lithuania before and after energy retrofit activities (improving the air tightness, thermal insulation, upgrade in HVAC systems).	Finland: 22.7 ± 8.4 μg/m³ Estonia: 16.8 ± 6.8 μg/m³ Lithuania: 27.4 ± 10.9 μg/m³	Finland: 20.3 ± 7.3 μg/m³ Estonia: 7.0 ± 0.8 μg/m³ Lithuania: 43.0 ± 15.0 μg/m³	Formaldehyde concentrations did not exceed the WHO guideline values in the measurement apartments. The observed both positive and negative differences in the gaseous pollutants concentrations in retrofitted buildings as compared to the non-retrofitted, the authors suggest that other factors than retrofitting may have effects on the concentrations. However, a strong conclusion cannot be drown due to a relatively small sample size.
Coombs et al. 2016	The study asses the indoor air quality in green-renovated vs. non-green low-income homes in Ohio, US. In total 42 homes were investigated, of which 14 were considered non-green, and 28 were green units. In eight of the homes, pre and post renovation IAQ measurement were conducted.	0.01 ppm (~12.3 μg/m³)	0.03 ppm (~36.9 μg/m³)	Formaldehyde concentrations were found to be significantly higher in homes immediately post renovation as compared to pre renovation. The authors associated increased formaldehyde levels after renovation with newly

				installed formaldehyde contain building materials (particle-board and plywood)
Frey et al. 2015	The study investigates the impacts of an energy efficiency retrofit on indoor air quality and resident health in a low-income senior housing apartment complex in Phoenix, Arizona. The renovation included energy efficiency upgrade in the HVAC system, bathroom fan, a range hoot exhaust fan, and doors and windows, low VOC flooring, natural wooden cabinetry and energy start kitchen appliances. The IAQ in the apartments were assessed before and immediately after the renovation. In addition one more measurement were conducted a year after the renovation.	39 ± 11 ppb (~47.9 ± 13.5 µg/m^3) with median of 38 ppb (~47 µg/m^3)	Immediately after: 42 ± 13 ppb (~51.6 ± 15.9 µg/m^3) with median of 43 ppb (~53 µg/m^3) After one year: 27 ± 7 ppb (~33.2 ± 8.6 µg/m^3) with median of 26 ppb (~32 µg/m^3)	The significant decrease of the formaldehyde concentrations in one year after the retrofitting actions, the authors connects with the replacement of the building materials and furniture with low VOC emitting ones during the renovation. However, in short term (immediately after renovation) the concentrations of formaldehyde increased regardless the low VOC emitting materials installed.
Du et al. 2015	The study assessed the indoor environmental quality in 82 apartments in Finland and 95 apartments in Lithuania scheduled to be renovated within next couple of years. None of the studied apartments were renovated during the study.	Finland: 17.47 ± 6.92 µg/m^3 (median: 16.58 µg/m^3) Lithuania: 23.16 ± 10.47 µg/m^3 (median: 21.25 µg/m^3)	-	The levels of formaldehyde measured in all of the studied apartments were significantly below the WHO recommended limit value of 100 µg/m^3.
Noris et al. 2013	The study assessed the indoor environmental quality benefits of 16 apartments serving low-income population in three buildings located in California, USA. The goal of retrofitting actions were simultaneously reducing the energy consumption and improving the indoor	4 – 113 µg/m^3 with median of 16.5 µg/m^3	5 – 51 µg/m^3 with median of 19.0 µg/m^3	The results showed overall improvement in IEQ when a package of retrofit measures is implemented in apartments to both save

	environment quality (IEQ). Retrofitting measures varied among apartments and included envelope sealing, installation of mechanical ventilation, roof and walls insulation, HVAC system upgrade.			energy and improve IEQ. Formaldehyde and NO_2 less consistent behaviour after retrofit.

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