MEASUREMENT OF POLLUTANT EMISSIONS IN TWO SIMILAR VERY LOW ENERGY HOUSES WITH CAST CONCRETE AND TIMBER FRAME

Franck Alessi*[1], Michael Sollaris[2]

1 CEA INES
50 avenue du lac Léman
73370 le Bourget du Lac, France
**Corresponding author: franck.alessi@cea.fr*

2 CEA INES
50 avenue du lac Léman
73370 le Bourget du Lac, France

ABSTRACT

This article is devoted to Indoor Air Quality (IAQ) in two low energy houses, with different frames (cast concrete (I-BB) and timber frame (I-OB)) built in platform INCAS of INES (National Institute of Solar Energy - in french: Institut National de l'Energie Solaire). In order to quantify pollutant emissions due to building materials and products, an experimental protocol consisted in stopping ventilation systems -"balanced ventilation"- of each house (a little before and during the measurement campaign), closing doors and windows, and not allowing occupant. Measurements started quickly after the end of construction: 70 days for I-BB and 224 days for I-OB. To measure IAQ, an experimental protocol was developed using continuous recorders (TSI Q-TRAK 7565 for CO_2, multi-gas PID monitor Graywolf with TG502 VOC Probe for TVOC, NO_2, O_3; KIMO KH200 KISTOCK for t_a and RH) and passive samplers (radial diffusive samplers Radiello® for specific VOCs - hydrocarbons and glycol ethers- and aldehydes). The duration of each measurement campaign was 7 days (from 02/04/2010 to 09/04/2010 for I-BB and from 23/05/2011 to 30/05/2011 for I-OB). Logging intervals for continuous recorders were 10 minutes. So that to estimate emissions due to building materials and eventual associated health effects, we focused on Volatile Organic Compounds (VOC: including specific VOCs and aldehydes) both with passive samplers Radiello® and continuous recorder Graywolf. Results reveal that in these low energy houses, building materials and products emit a great quantity of VOC with an indoor concentration 7 times higher than outdoor levels (both for I-OB and I-BB). Each frame has a main pollutant: Toluene for I-BB with a concentration almost twice higher than WHO guideline value (260µg/m^3, 7days), and hexanal for I-OB : averaged value around 570 µg/m^3 against ≈ 140 µg/m^3 for I-BB. This study confirms clearly the importance of ventilation systems in these new low energy buildings and in general rules. If well dimensioned they should improve energy efficiency in order to increase IAQ, comfort and human well being.

KEYWORDS

Indoor Air Quality; Chemical pollutants; Pollution; Outdoor air; TVOC; VOCs; Aldehydes; Concentration; Measurement campaign; Continuous recorder; Passive sampler; Platform INCAS; Frame; Cast concrete; Timber frame; Building materials, Products; Health effects.

INTRODUCTION

The Indoor Air Quality in low energy buildings should be a preoccupation in order to minimize health risks for occupants. For several decades the air exchange rate has been reduced and the leakage of dwellings has also decreased [1]. Moreover, building materials hold several chemical products unknown in term of health effects. Consequently, ventilation systems are very important to dilute indoor air pollutants in order to minimize health risks for occupants. Unfortunately in France, ventilation is sometimes inadequate for many reasons: a complex regulation, too many workers (both in construction of installation), a poor or nonexistent maintenance, and an impact of renovation and rehabilitation unappreciated [1].

A Recent article of OQAI ("Observatoire de la Qualité d'Air Intérieur") has shown that the air exchange rate in French houses is less than the prescribed rate for 56% of them [2] and it doesn't depend on ventilation systems (mechanical ventilation, natural ventilation,…). [2]

Despite an extensive literature search, it appears that a similar approach has never been followed until now. For other studies conducted so far, the VOC concentrations measured are the result of the presence of multiple sources of pollution (materials, equipments, furniture, household products, human activities, external environment...). This study is going to determine with more certainty the impact of construction materials and products on indoor air pollution.

Volatile Organic Compounds (VOC): Organic compounds with boiling points ranging from a lower limit between 50 °C and 100 °C, and an upper limit between 240 °C and 260 °C, where the upper limits represent mostly polar compounds. NOTE: in this article VOC includes VOCs (glycol ethers and hydrocarbons) and aldehydes (formaldehyde, acetaldehyde…) (Table 2).

The study was conducted with an experimental protocol different from already made national and international studies [3,4,5,6,7,8,9]. Having two experimental homes with ventilation systems stopped, closed windows and doors, identical geometries, but different frames allowed us to quantify VOCs and aldehydes emissions emitted by products and building materials.

The study focuses on the houses of the platform INCAS from INES (Institut National de l'Energie Solaire – National Institute of Solar Energy) in Le Bourget du Lac (Savoie - 73).

There are currently 3 un-inhabited 110m² houses (an additional one is under planning), with the same internal geometry, same architecture, same level of insulation (Figure 3), and located under the same climate, therefore with the same solar inputs. The three houses are respectively made of concrete blocks (house I-DM), cast concrete (house I-BB) and timber frame (house I-OB), with different insulation technical and materials in order to comply with the "Passivhaus" energy standard (less than 15 kWh/m² heating needs per year). Note that measurements on Indoor Air Quality (IAQ) were only done in I-OB and I-BB houses.

The experimental protocol is based on the work of the OQAI for the selection of pollutants to target [3].Chosen Pollutants are the same as in this investigation in order to have a magnitude of expected concentrations. In 2010, a campaign measurement was realised in I-BB house (from 02/04/2010 to 09/04/2010) and a second (I-OB) was done from 23/05/2011 to 30/05/2011.

Figure 1. Houses INCAS I-BB, I-DM and I-OB.

MATERIALS AND METHODS

In this article we are focusing on two un-inhabited 110m² houses of the platform INCAS: I-BB and I-OB. The goal : quantifying the level of indoor pollutants of I-BB (made of cast concrete) and I-OB (made of timber frame) due to building material emissions without ventilation, occupant, and with low leakage paths (permeability values for Passivhaus label : N_{50} = 0.54 Vol/h for I-OB and 0.26 Vol/h for I-BB). All measurements were realised during a week (7 days). The main logging interval used for the recorders was 10 minutes.

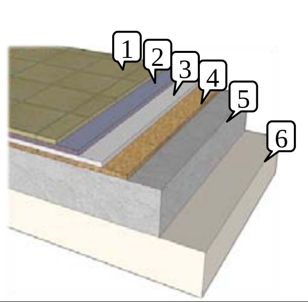
Building description

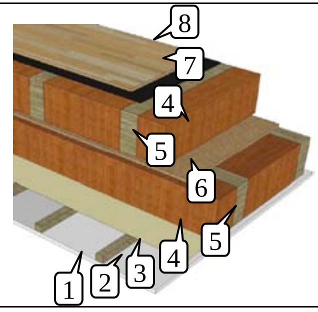
I-BB and I-OB houses were equipped with a balanced ventilation (BV). This system is a mechanical equipment which integrates a heat exchanger combined with a ventilation system. To characterize precisely pollution from building materials and products, this BV system was stopped. Consequently, indoor pollutant levels increased.

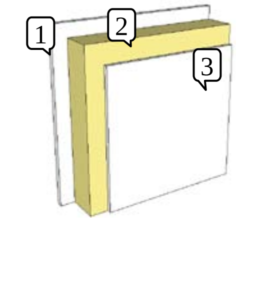
So that to describe I-BB and I-OB building materials and to identify their different pollutant sources (Table 1), we realised an investigation based on a French standard [10].

I-BB house was built with cast concrete walls and coated with a 20 cm extruded polystyrene exterior insulation. There was a reinforced concrete slab on the basement insulated with polyurethane and a concrete slab on the underside of the first floor ceiling insulated with glass wool as well as the gable walls. The linings were tiles on

the ground floor and PVC on the second floor. On the walls, gypsum board covered with a paint solvent ensured the finishing touches. For the ceiling of each floor, gypsum blocks were placed.
For I-OB house, walls had well spread wood wool insulation. A reinforced concrete slab was placed on the basement insulated from the underside by polyurethane. The floor of the first floor and the ceiling were made of wooden beams and wood chipboard. The same finishing touches were done for the house I-BB : tiled floor on the ground floor, covering vinyl PVC -Polyvinyl chloride- on the first floor (except in the bathroom : tiles), ceiling with gypsum blocks and on the walls gypsum board plus paint solvent.







Ground floor	Ceiling of first floor	Walls	Interior Walls
1: Tiled floor + glue (1cm) 2: Gifafloor knauf® (2,5cm) 3: Phenolic foam (3,0cm) 4: Insulation pellets (2,4cm) 5: Reinforced concrete(18cm) 6: Polyurethane (14cm)	1: Gypsum blocks (1cm) 2: Wooden slats (6,4cm) 3: Vapor barrier 4: Wood wool (2 x 24cm) 5: Wooden beam (2 x 24cm) 6: Wooden chipboard (1,9cm) 7: Rain barrier 8: Wood flooring (2cm)	1: Roughcast (0,6cm) 2: Polystyrene (3cm) 3: Wooden chipboard (2,5cm) + Cement 4: Rain barrier 5: Wood wool(22cm) 6: Vapor barrier 7: Wood wool(16cm) 8: Wooden chipboard(1,6cm) 9: Gypsum board (1cm)	1: Gypsum board (1cm) 2: Wood wool (5cm) 3: Gypsum board (1cm)

Table 1. Description of building materials use in I-OB (timber frame).

This study is only considering the pollutant emissions in indoor air due to the first layers of materials and paints (interior faces).

Measurement materials

Carbon dioxide (CO_2) was measured thanks to TSI Q-track 7565 with a probe “IAQ Probe Model 980”. It is a continuous recorder. CO_2 is an index of confinement in office buildings. It permits to check the ventilation system efficiency. In this study the protocol didn’t allow human presence during the measurement campaigns. Moreover, no sources of burning were present in buildings, the balanced ventilation was stopped during the week of the campaign. The monitoring of carbon dioxide got information about the behaviour of the I-BB and I-OB houses when ventilation system was off, doors and windows closed, no occupant.
Temperature (t_a) and relative humidity (RH) in the air were continuously measured (KIMO KH200 KISTOCK) at the centre of each house room, at a height of 1.2 m directly above the floor close to radial diffusive samplers Radiello®. This information is very important because Total Volatile Organic Compounds (TVOC), Volatile Organic Compounds (VOCs) and aldehydes emissions increase when the temperature increases [11].
So that, to characterise building material emissions, a continuous recorder (multi-gas PID monitor Graywolf with TG502 VOC Probe) was used to measure the global level of TVOC, Nitrogen dioxide (NO_2) and Ozone (O_3). Considering the surface and the number of rooms of each house (I-BB and I-OB), it was impossible to position a TVOC continuous recorder in each room. These measurements were made at the centre of the biggest area of I-BB and I-OB: “kitchen/living room” at a height of 1.2 m above the floor. The PID monitor was positioned on an anodized aluminium desk to avoid chemical emissions due to this table.
In addition, radial diffusive samplers Radiello® were used to measure specific chosen VOCs and aldehydes in each house room (Cf. Table 2). Moreover, radial diffusive samplers were placed on air inlet of the air system supplier so that to estimate the difference of concentration between indoor and outdoor air. Measurements on Indoor Air Quality (IAQ) for specific VOCs and aldehydes in I-OB and I-BB houses have been based on OQAI study “Campaign National Homes: State of Indoor Air Quality in French dwellers”[3]. Pollutants chosen were the same as in this investigation in order to have a magnitude of expected concentrations.
With these specific measurements, we have attempted to identify different building material sources and associated health effects. The concentrations of VOCs and aldehydes were calculated on a sampling period of a

week (the duration of measurement campaigns). All chemical analysis were realised by the Fondazione Salvatore Maugeri. Aldehydes were analysed by High Performance Liquid Chromatography (HPLC) and VOCs by a Thermal Desorption system attached to a Gas Chromatograph with Flame Ionisation Detector (TD/GCFID).

VOCs				**Aldehydes**	
Hydrocarbons	*SOURCES*	*Glycol Ethers*	*SOURCES*		*SOURCES*
Benzene	glue, interior paint, plasticizer, maintenance products	1-methoxy-2-propanal	interior paint, varnish, fungicide, herbicide, wood treatment, silicone clog	Formaldehyde	wooden panel, fiberboard, crude wood panel, solvent paint, tobacco smoke
Toluene	interior paint, glue, ink, carpet, silicone clog	2-butoxyethyl acetate		Acetaldehyde	tobacco smoke, crude wood panel, wooden panel
Ethylbenzene	fuel, solvent, pesticide	1-Methoxy-2-propyl acetate		Acrolein	burning, tobacco smoke, drippings
m/p-xylene	interior paint, varnish, insecticide	2-butoxyethanol		Propanal*	solvent paint
Styrene	plastic material, heat insulation, fuel, tobacco smoke			Butanal*	wooden panel, parquet treatment
o-xylene	interior paint, varnish, insecticide			Benzaldehyde*	solvent paint, parquet treatment
n-decane	white spirit, floor glue, wax, wood varnish, cleaner, carpet			Isopentanal*	parquet treatment, wooden panel
1,2,4 trimethylbenzene	oil solvent, fuel, tar, varnish			Pentanal*	solvent paint, wooden panel
n-undecane	white spirit, floor glue, wax, wood varnish, cleaner, carpet			Hexanal	wooden panel, solvent paint, wood working, crude wood panel

Table 2. Choice of specific VOCs and aldehydes and theirs relative sources in order to quantify emissions due to building materials (*not taken into account in campaign national homes [3])

Thanks to the investigation based on a French standard in I-BB and I-OB, we noted that there are more potential sources of pollutants into the house I-OB. Because the I-OB house is made of wood, wood wool, wooden chipboard, ..., (Table 1) which are organic materials and therefore VOC emitters. Whereas I-BB has an exterior insulation which doesn't emit pollutant inside the home and its frame is made of cast concrete which is an very low VOC emitters.

RESULTS

Results of carbon dioxide concentration confirm that air inlets are very small. For I-BB and I-OB, the measurement campaigns show a higher CO_2 concentration of 200ppm between the outside and inside air. Moreover, indoor variation of carbon dioxide is not correlated with outdoor concentrations (Figure 2). Furthermore, Figure 2 shows a CO_2 level inside the houses below the background noise led us to put forward two hypothesises. Firstly, there is a CO_2 sink due to indoor materials, chemical reactions,… [12]. Secondly, there is a sedimentation/stratification of the CO_2 concentration because of its gas density (d=1,53v [13]). We expected a gradient concentration between the floor and the ceiling with a higher concentration close to the ground. (Note that a measurement campaign was realised to check this phenomenon but the uncertainty of measurements due to continuous recorders used, was too big to validate this hypothesis).

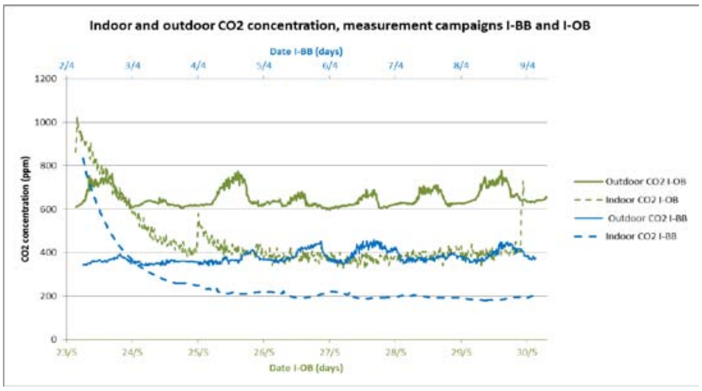


Figure 2 : Variation on a week of indoor and outdoor CO_2 concentration both for I-BB and I-OB.

During measurement campaigns, ozone (O_3) was measured at concentrations below the Detection Limit (DL) of the Graywolf device (DL=40µg/m^3). Outdoor averaged values measured by AASQA[1] 'Air APS' were higher than DL (60.2µg/m^3 for I-BB and 81.9µg/m^3 for I–OB). As a result, low indoor level of O_3 was certainly due to reactions with VOCs [2], building materials and products. Furthermore, impact of photochemical pollution on indoor air quality was studied during the summers of 2003 and 2004 in MARIA CSTB experimental house [14]. About 80% to 95% of the ozone was removed inside the room, showing the presence of major ozone sinks. [14]
Nitrogen dioxide (NO_2) was also measured below the detection value of the Graywolf material. As ozone gas, it is involved in chemical reactions with VOC [12].
In order to have continuous information about the TVOC concentration, a Graywolf PID monitor was used. Its goal was to obtain on the one hand, an historical every ten minutes to show the trends of these pollutant concentrations, and on the other hand, to quantify a global level of TVOC in real time. It was a further approach in regards with radial diffusive samplers Radiello®. This passive method gives an averaged concentration value on the duration of the measurement campaign for each compound targeted. As a result it is impossible to notice different variations of level during nights and days unlike PID Monitor. However the PID monitor doesn't permit to identify an emitting source produced by building materials for a given level of TVOC. This device takes into account a sum of several hundred volatile pollutants (including VOCs and Aldehydes, Table 2).
That is why we used these two different methods to get a global approach in order to identify different sources and associated health effects (when possible).

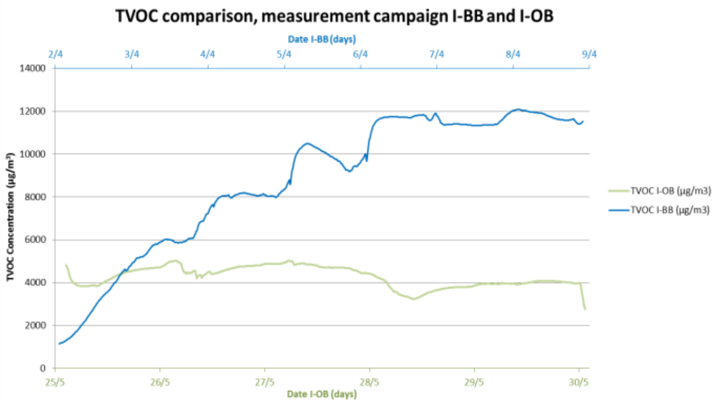


Figure 3. Variation on a week of TVOC in I-OB and I-BB houses.

Figure 3 shows the trends of the emissions of TVOC in I-BB and I-OB houses. The average TVOC concentration equals 4,3mg/m^3 for I-OB against 8.8mg/m^3 for I-BB. These values are very high compared to guideline values found in articles (e.g.: 0.3mg/m^3 in Deutschland [15]).
Even if I-BB TVOC concentration is multiplied by 2 compared to I-OB, the difference between these 2 concentrations might come from several causes: firstly the period of time between the end of the construction and the measurement campaigns is three times longer for I-OB than I-BB (respectively 224 days to70 days), secondly ventilation systems weren't exactly stopped at the same time before the I-OB and I-BB campaigns (2 days before for I-OB and at the beginning of the measurements for I-BB). Consequently, pollutants were more diluted. Unfortunately, it is difficult to conclude about the origin of these high concentrations and difference

[1] AASQA : Association Agréée de Surveillance de la Qualité de l'Air

between these 2 frames at this step of the study because of the average temperature difference (Figure 4) between I-OB and I-BB which equals $\approx 10°C$ ($\overline{t_{aI-OB}} \approx \overline{t_{aI-BB}} + 10°C$). Note that an increase of temperature has impacts on VOC emissions [11].

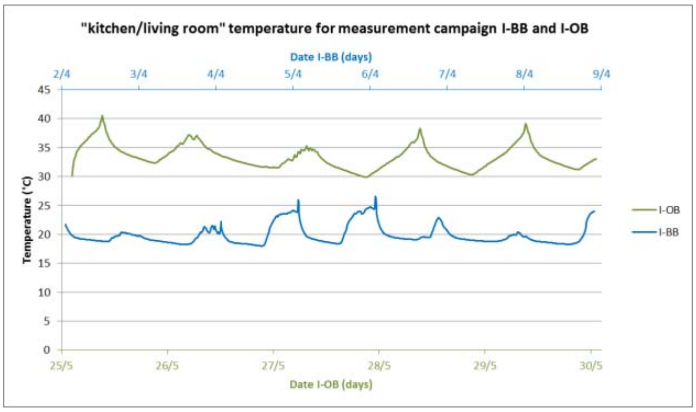


Figure 4. Variation of air temperature (t_a in °C) in I-OB and I-BB houses during the measurement campaigns (a week).

About specific VOCs and Aldehydes, in a first time we were compared the sum of VOCs concentrations (Table 2 : list of VOCs and chosen aldehydes) obtained with passive samplers in each room of I-BB and I-OB. Then the same protocol was realised for Aldehydes (Figure 6).

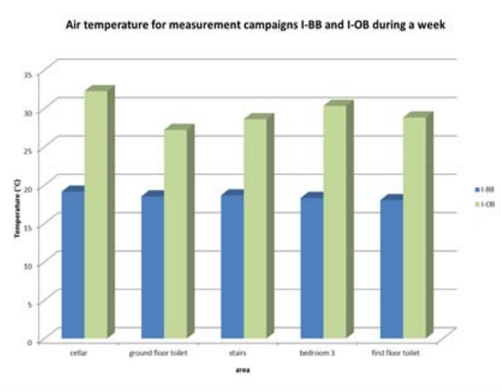


Figure 5. Examples of air temperature averaged on a week (only rooms equipped with air temperature KIMO KH 200).

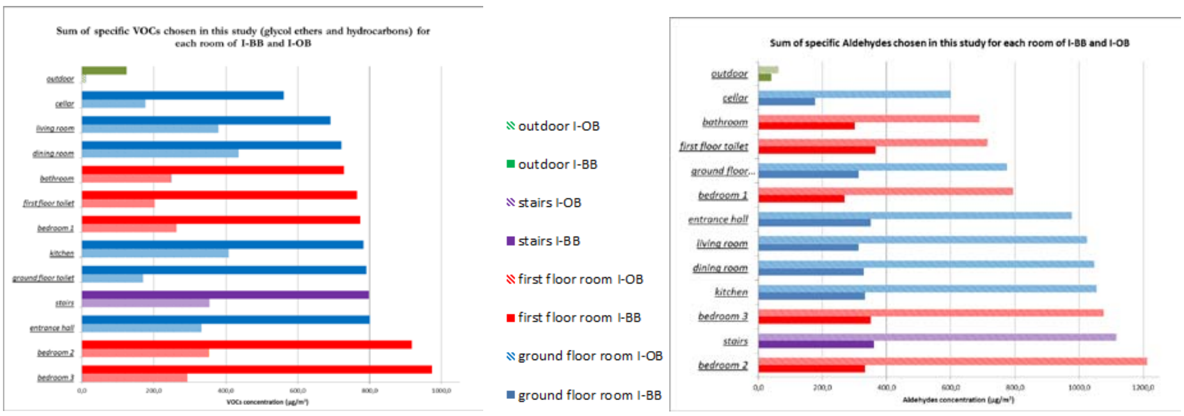


Figure 6. On the left : Sum of specific VOCs targeted, values obtained and averaged on a week, and for each room (I-OB and I-BB) ; On the right: sum of specific aldehydes targeted, values obtained and averaged on a week, and for each room (I-OB and I-BB).

The difference between the sum of the indoor VOCs and outdoor is significant and is multiplied by 7: $[VOCs]_{indoor} \approx 7\ [VOCs]_{outdoor}$. Moreover, the VOCs concentration in I-BB is approximately homogeneous [16] in each

room but it is not the case in I-OB (Figure 6). Furthermore, in I-OB the average concentration is two times as small as I-BB. To finish, except the stairs and the entrance hall in I-OB, we observe that each room with south exposure has a higher concentration in VOCs certainly because of a higher air temperature in these areas [11].
Figure 6 shows again a difference between indoor and outdoor aldehydes concentrations: $[\text{Aldehydes}]_{\text{indoor}} \approx 7\,[\text{Aldehydes}]_{\text{outdoor}}$. However and contrary to the sum of VOCs concentration, the level of aldehydes in I-OB is higher than I-BB.
In a second time, we were detailed the value of measurements of each VOCs and aldehydes during the campaign, in each room of I-BB and I-OB in order to obtain their specific levels and their associated health effects with their associated current guideline values (when they exist).

Results for specific VOCs:

Each concentration of chemical pollutants measured by radial diffusive samplers Radiello® is shown on Figure 7 below. On these histograms it is possible to visualize the variations of specific VOCs in different rooms of I-BB and I-OB houses. Note that the value of concentration is averaged on 7 days (duration of measurement campaigns).

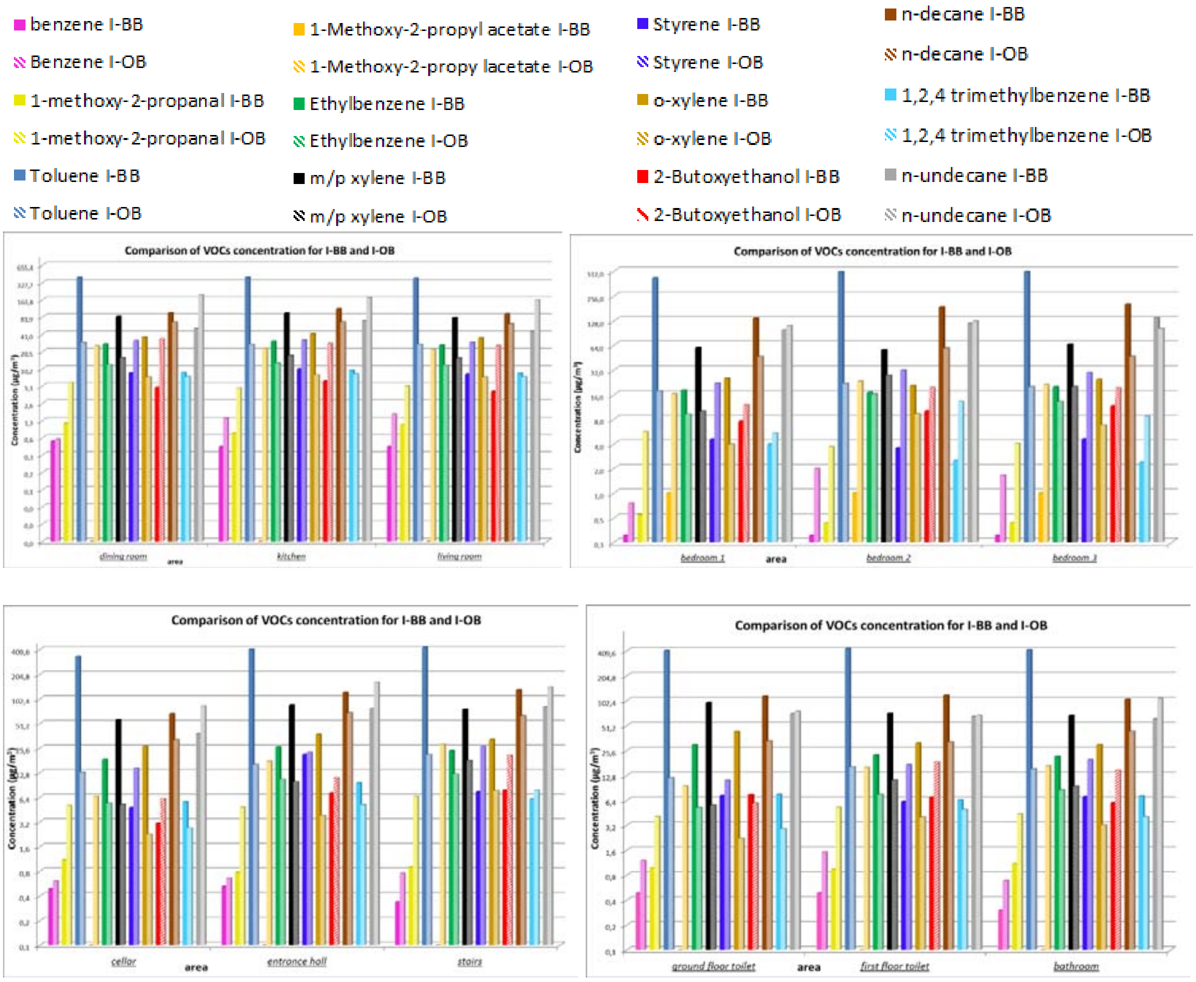


Figure 7. Comparison in each room of I-OB and I-BB houses of specific VOCs concentrations thanks to passive samplers RADIELLO® (averaged values on a week per pollutant).

Glycol ethers (Table 2) had a higher concentration in I-OB than I-BB probably due to woodworking products and fungicides. Moreover, outdoor concentrations about glycol ethers were negligible (between 0 and $0.2 \mu g/m^3$). Consequently, we may estimate that emissions were linked to building materials.

	Measurement campaign		WHO	OQAI Values (µg/m³)			Health Effects
	Maximum value **I-BB** **(µg/m³)**	Maximum value **I-OB** **(µg/m³)**	Guideline values	Median	90th percentile	maximum	
1-methoxy-2-propanal	1,2	6,5	*No value*	1,9	10,8	170,1	Eyes and breath soreness
1-methoxy-2-propylacétate	<DL (2)	**28,3**	*No value*	<DL	<QL (3)	39,5	Eyes and breath soreness
2-butoxyethanol	**11,4**	**34,2**	*No value*	1,6	5,5	60,6	Hemolitic anaemia
2-butoxyethyl-acétate	<DL	**2,1**	*No value*	<DL	<DL	12,2	Eyes and skin soreness

Table 3. Averaged values of glycol ethers and associated health effects (from measurement campaigns I-OB and I-BB, and OQAI campaigns plus WHO guideline values [17]).

For three Glycol ethers (1 methoxy-2-propanol, 1-methoxy-2-propyl acetate and 2-butoxyethanol), measured concentrations in I-OB were higher than the 90th percentile of the OQAI campaign national homes [3], this means that 90% of measured values in French homes were below the levels found in I-OB. Products of wood processing and fungicides used in building materials (frame, particle boards, raw wood panels, wood wool, ...) were certainly the sources responsible for these high levels.

	Measurement campaign		WHO	OQAI Values (µg/m³)			Health effects
	Maximum Value **I-BB** **(µg/m³)**	Maximum Value **I-OB** **(µg/m³)**	Guideline values (µg/m³)	Median	90th percentile	maximum	
Benzene	0,9	2	30(7 days)	2,1	5,7	22,8	Bone marrow affected,
Trichloroethylene	0,1	0,1	20 (chronic exposition)	1	3,3	4087,2	Psycho organic syndrome, skin soreness
Toluene	**504,1**	29,5	260 (7days)	12,2	46,9	414,2	Central nervous system effect, somnolence, headache
Tetrachloroethylene	0,1	0,6	250 (chronic exposition)	1,4	5,2	684,3	Soreness, neurological disease, renal effects, hepatic effects
Ethylbenzene	**31**	**16,2**	*No value*	2,3	7,5	85,3	Lung and liver cancer
(m+p) xylene	**96,4**	**27,4**	4800 (24h)	5,6	22,0	232,8	Headache, giddiness
o-xylene	**43**	**9,2**	4800 (24h)	2,3	8,1	112,3	Headache, giddiness
Styrene	**21,3**	**32,5**	260 (7 days)	1	2	35,1	Eyes and lung soreness
n-decane	**202,1**	**68,3**	*No value*	5,3	29,1	1774,1	No estimate
1,2,4-trimethylbenzene	9,6	13	*No value*	4,1	13,7	111,7	Breath soreness
1,4 dichlorobenzene	<DL	0,1	*No value*	4,2	68,5	4809,8	Lung soreness and cancer
n-undecane	**139**	**199,2**	*No value*	6,2	33,6	502,1	No estimate

Table 4. Averaged values of hydrocarbons and health effects obtained by passive samplers (results of measurement campaigns in I-BB and I-OB, and OQAI campaigns plus WHO guideline values [17]).

Toluene was the higher value of hydrocarbons measured in I-BB house. We can't explain it. This high level was found everywhere in the I-BB house. The average value on 7 days was 504µg/m³ compared to 29.5µg/m³ for I-OB. Currently the WHO guideline value on 7 days is 260µg/m³. Paints, glues and varnishes were certainly the products responsible for these high concentrations. In I-BB and I-OB, five other compounds had high concentrations compared to OQAI study: ethylbenzene, (m + p) xylene, o-xylene, styrene, n-decane and n-undecane.

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(1) Detection Limit
(2) Quantification Limit

Results for specific aldehydes:

Each concentration of chemical pollutants measured by radial diffusive samplers Radiello® is shown on Figure 8 below. On these histograms it is possible to visualize the variations of specific aldehydes in different rooms of I-BB and I-OB houses. Note that the value of concentration is averaged on 7 days (the duration of measurement campaigns).

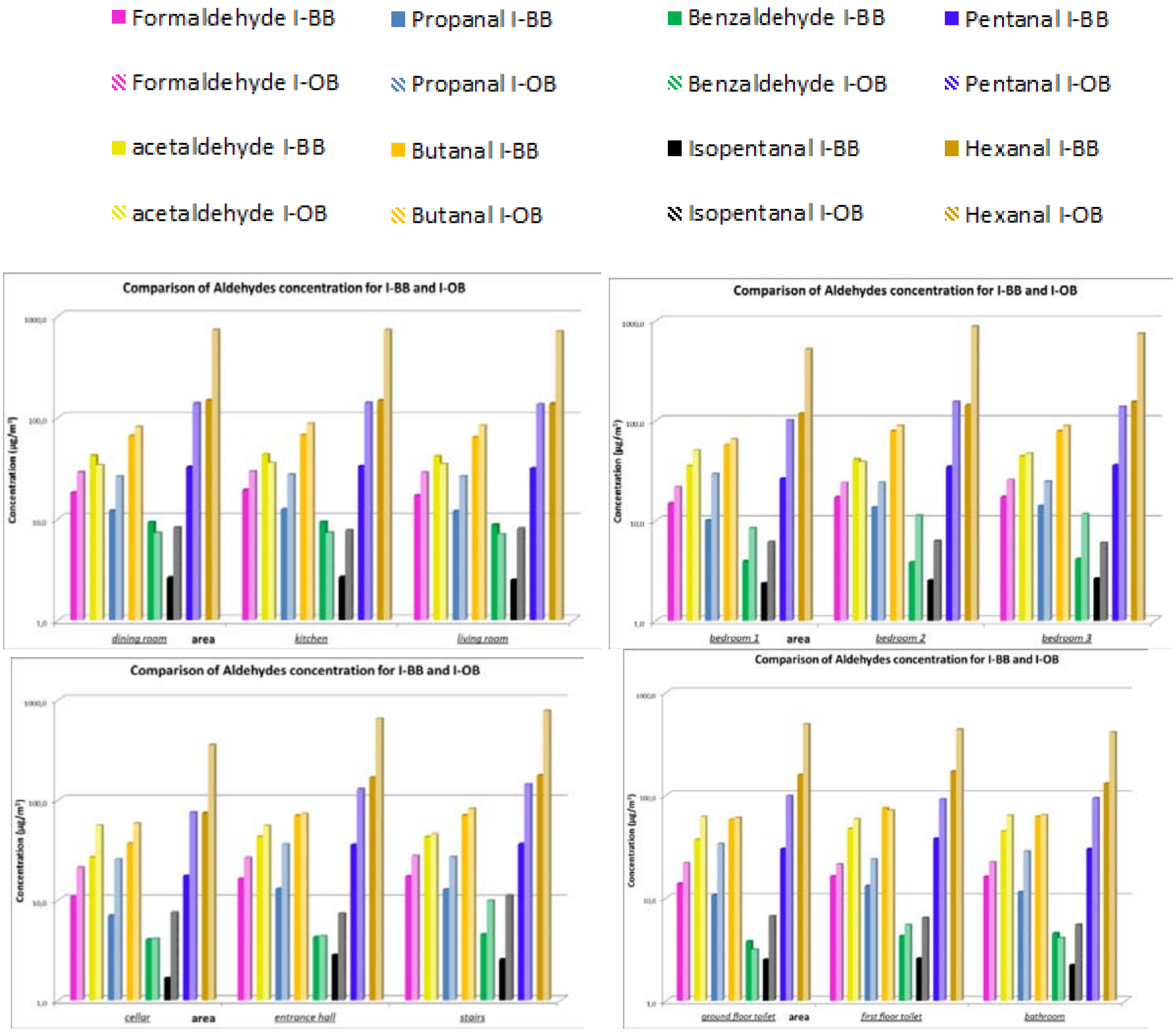

Figure 8. Comparison in each room of I-OB and I-BB houses of specific aldehydes concentrations thanks to passive samplers RADIELLO® (averaged values on a week per pollutant).

The concentration of aldehydes was higher in I-OB than I-BB for all pollutants (excepted acrolein). Note that the aldehydes come from mostly wood materials (raw wood panels, particle boards...), so the higher concentration in the house I-OB makes sense. The hexanal was the pollutant found in greater quantities at each site with an average of 140µg/m^3 for I-BB and 570.7µg/m^3 for I-OB. Bedroom 2 of I-OB had the maximum value. It was twice the maximum measured in French study “Campaign National Homes” by OQAI [3]. It was a very high value. A study[18] revealed that Hexanal represented 21% of indoor air pollutant emissions whereas in I-OB campaign, hexanal represented 60% of the total concentration of pollutant. Currently health risks due to this pollutant are poorly understood but skin irritation, eye and respiratory symptoms are related to hexanal [19]. A recent article [2] confirmed a high presence of hexanal in low energy buildings made of timber frame. No guideline value exist for this compound, however, the national campaign of OQAI [3] indicated a median value of 13.6 µg/m^3, 10 times less than in I-BB and 40 times less than I-OB.

Main sources of hexanal come from particle boards, woodworkings and paint solvents. That is why the wooden staircase of the house I-OB had the highest concentration of hexanal (863.6 µg/m^3).

	Measurement campaign		WHO	OQAI Values (µg/m³)			Health effects
	Maximum Value **I-BB** **(µg/m³)**	Maximum Value **I-OB** **(µg/m³)**	Guideline value (µg/m³)	Median	90th percentile	maximum	
Formaldehyde	**19,1**	**29,3**	50 (2 h) 10 (1year)	19,6	39,9	86,3	Eyes nose and lung soreness, asthma
Acetaldehyde	**46,9**	**63,1**	*No value*	11,6	24,3	94,6	Eyes nose and lung soreness, asthma
Acrolein	<0,1	<0,1	*No value*	1,1	2,6	12,9	soreness
Propanal	14,1	35,9	*No value*	-	-	-	Ocular lesion
Butanal	78	88,7	*No value*	-	-	-	soreness
Benzaldehyde	9,4	11,6	*No value*	-	-	-	Eyes nose and lung soreness, asthma
Isopentanal	2,8	11,0	*No value*	-	-	-	Eyes nose and lung soreness, asthma
Pentanal	37,8	154,9	*No value*	-	-	-	Eyes nose and lung soreness, asthma
Hexanal	**174,6**	**863,6**	*No value*	13,6	35,6	368,5	Headache, eyes nose and lung soreness, asthma

Table 5. Averaged values of aldehydes and associated health effects obtained by passive samplers (results of measurement campaigns in I-BB and I-OB, and OQAI campaigns plus WHO guideline values [17])

CONCLUSION

The protocol of this study was developed to quantify the pollutant emissions due to building materials and products with no balanced ventilation, with closed doors and windows and without any occupant. These two low energy buildings with two different frames (cast concrete and timber frame) were studied in order to determine emission sources, level of chemical pollutants of each dwelling, and associated health effects (when feasible).
Carbone dioxide measurements reveal “strange” values below the CO_2 outdoor background noise. We think that this phenomenon is due to either a sink effect or a stratification of CO_2 between floor and ceiling.
Ozone and nitrogen dioxide are below the detection limit. Perhaps, there is a sink effect due to chemical reactions with VOC gases and building materials for O_3.
The sum of glycol ethers, of hydrocarbons, and of aldehydes has highlighted that concentration of these groups of chemical pollutants is homogeneous enough in each room of I-BB and a bit less than in I-OB. In general rules, we determined that emissions of chemical volatile compounds were higher in Southern rooms of I-OB certainly due to different weather conditions and the average of indoor air temperature ($\overline{t_{aI-OB}} \approx \overline{t_{aI-BB}} + 10°C$). Furthermore, both for I-BB and I-OB houses, the indoor VOCs emissions were multiplied by 7 compared to outdoor pollution ($[VOCs]_{indoor} / [VOCs]_{outdoor} \approx 7$).
The studies of two houses show that I-OB had more sources of pollutants and the concentrations of aldehydes and glycol ethers were higher.
As well, we noted a very high concentration value in toluene (504.1 $\mu g/m^3$) for I-BB. This pollutant level is almost twice greater than guideline value recommanded by WHO (260$\mu g/m^3$ of 7 days). These high concentrations are certainly due to paints, glues and varnishes. This rate might (260$\mu g/m^3$) cause headaches, somnolence.... Similar effects have been perceived in I-OB house by engineer but we think that hexanal may have caused these symptoms (toluene average concentration in I-OB was low and below its guideline value). Note that hexanal pollutant was found in each room at a very high level.
However, it is very difficult to associate pollutants emitted by sources to health effects in this article. In fact, a health effect may have several sources and a building material source may have several health effects.
Moreover, current studies realized in I-BB and I-OB show that the ventilation systems when operating drastically remove pollutants (hydrocarbons and aldehydes concentrations were removed up to 75% and 70% respectively for I-BB and I-OB).
Despite the same protocol used for I-OB and I-BB campaigns, it is very difficult to compare emissions arising from these different frames because air temperature is higher in I-OB than I-BB ($\approx$10°C) and measurements started on the one hand 70 days after the end of construction for I-BB and on the other hand 224 days for I-OB.
To conclude, in these low energy consumption buildings with very little leakage paths, it is very important to use ventilation systems well dimensioned, with good maintenance, in order to ensure the recommended air exchange rate. Currently, energy efficiency is not the only parameter to watch. That is why, to get a global approach relating both occupant comfort and energy efficiency, indexes of Indoor Environment Quality (indoor

air quality, visual comfort, acoustic comfort, thermal comfort) must be taken into account, monitored, regulated, as soon as possible when designing low energy buidings.

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