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IMPACT OF CONTAMINATED INTERIOR FINISHING MATERIALS ON THE EDUCATIONAL BUILDINGS

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Indoor environmental quality, Health environment, Occupants satisfaction, Formaldehyde contaminations, Volatile organic compounds.

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Abstract

This paper focuses on the impact of indoor finishing material contaminations such as Formaldehyde (HCHO) and Volatile organic compounds (VOCS). These contaminations are reflected through harmful effects on the health of occupants in the indoor environment, reflecting negatively on the comfort, satisfaction, and productivity of inhabitants in the indoor environment. The research focuses particularly on educational buildings as a case study and the effect of contaminations in a design studio located in a faculty building of a university in Debbieh, Lebanon. During the first year of building use, the study checked the concentration of (HCHO) and (VOCS) through the use of an air quality meter in different periods of time. Following the tests, the study implemented a new method to discharge contaminations prior to occupants using the building. This document leads to the technical process to release contaminations, becoming a guideline for further professional practice. The research combines theoretical with the applicable methods to offer the best practices for releasing such contaminations.

Keywords

Indoor environmental quality, Health environment, Occupants satisfaction, Formaldehyde contaminations, Volatile organic compounds.

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ABSTRACT: This paper focuses on the impact of indoor finishing material contaminations such as Formaldehyde (HCHO) and Volatile organic compounds (VOCS). These contaminations are reflected through harmful effects on the health of occupants in the indoor environment, reflecting negatively on the comfort, satisfaction, and productivity of inhabitants in the indoor environment. The research focuses particularly on educational buildings as a case study and the effect of contaminations in a design studio located in a faculty building of a university in Debbieh, Lebanon. During the first year of building use, the study checked the concentration of (HCHO) and (VOCS) through the use of an air quality meter in different periods of time. Following the tests, the study implemented a new method to discharge contaminations prior to occupants using the building. This document leads to the technical process to release contaminations, becoming a guideline for further professional practice. The research combines theoretical with the applicable methods to offer the best practices for releasing such contaminations.

KEYWORDS: Indoor environmental quality, Health environment, Occupants satisfaction, Formaldehyde contaminations, Volatile organic compounds.

1. INTRODUCTION

The human population spend most of its time indoors, and a large percentage of the population of the world lives and works in urban areas and office settings. (ASHRAE, 1993). Indoor Environmental Quality (IEQ) studies undertaken by various scientists shows that the health and productivity of buildings inhabitants is greatly affected by air quality, illumination, acoustics, and thermal comfort (Joon-Ho Choi, 2016).

The IEQ-and occupant satisfaction variables can be split into physical and non-physical variables as shown in figure 1. The physical variables generally comprise four components: thermal comfort, indoor air quality, lighting and acoustic environment, which can be assessed by measurable parameters. In general, non-physical variables refer to indoor qualities that are difficult to measure by instrumentation, such as layout, privacy, furniture, cleanliness, facilities and view (Joon-Ho Choi, 2016) . In previous researches, the physical variables were more commonly studied in comparison to non-physical variables due to their capacity to be quantified (Yang Geng 2019).

There are two to five more pollutants in indoor air than in outdoor air (EPA, 2013). Overall, the indoor experience is regarded as the indoor environmental quality. Problems with IEQ can contribute to issues with liability, bad occupant health, workdays missed, and costly repairs to remedy. Think of a person selling a house and a potential buyer finds black mold in the basement. Either the dealer will pay the cleaning, or the property will not be sold. In terms of good IEQ, it includes every aspect of building process: design, building practice, selection of materials, housekeeping, operations and maintenance, staff training, occupant habits, etc. All these variables affect the indoor environment and buildings' users. (USGBC, 2016).

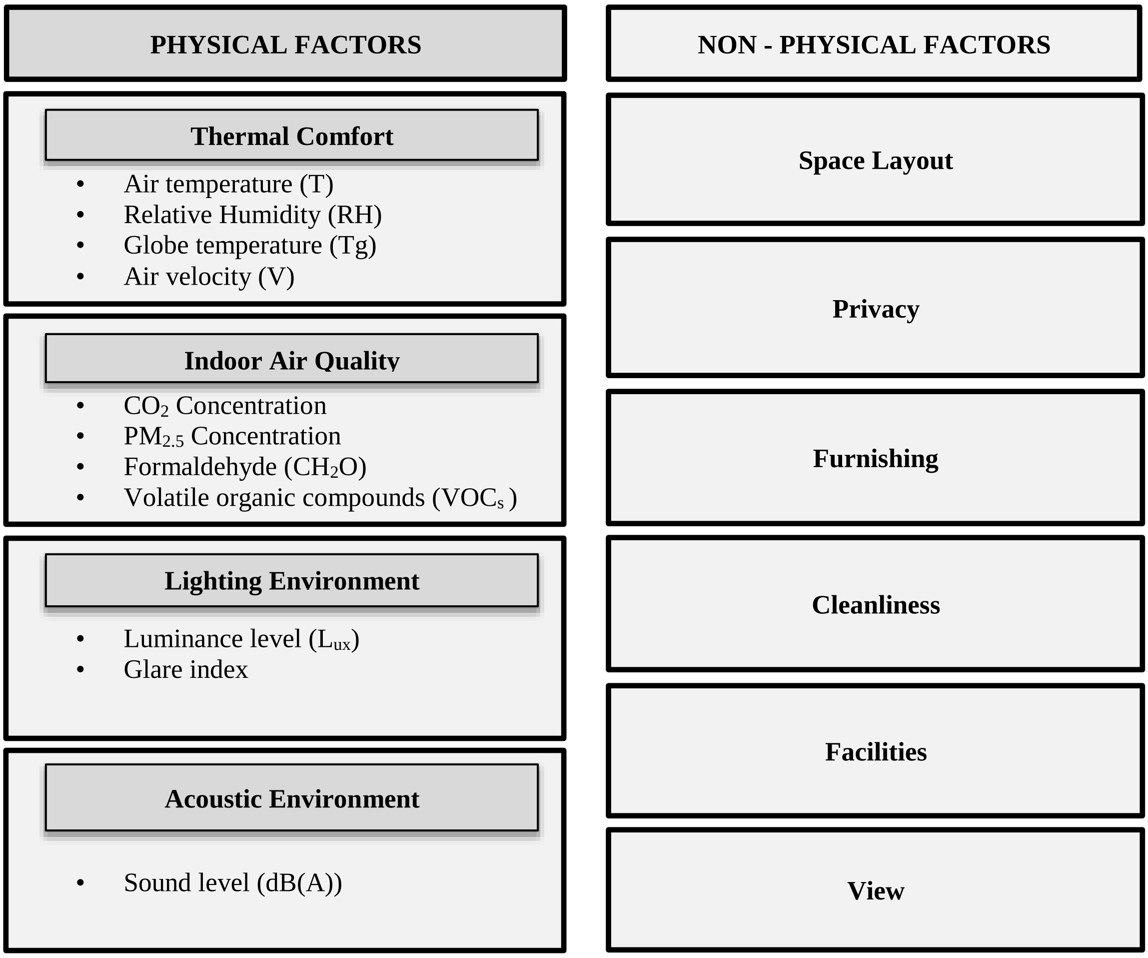


Fig.1: Physical factors and non-physical factors in IEQ studies.
Reference: (Yang Geng 2019)

On average, people spend 90 percent of their time indoors, so it is that they breathe good clean air. The expression "sick building syndrome" (SBS) describes situations where the occupants in a building experience severe health and comfort repercussions associated with time spent in a building but cannot identify a specific disease or cause. One of the most efficient means of removing contaminants from a space is to prevent them from getting indoors in the first place. The process starts in the project design stage and goes on through operations and maintenance–our entire design of buildings and an integrated team approach. Controlling the source of the contaminants can be very cost-effective (USGBC, 2016).

Air contaminants can take many forms:

- Dust and contaminants from the building process
- Second-hand smoke
- CO2
- Material off-gassing (for example: formaldehyde and other volatile organic compounds (VOCs))
- Radon
- Chemicals
- Particulates

Formaldehyde and other volatile organic compounds (VOC) are becoming more and more concerning about their impact on human health. A typical household holds 185 gallons of adhesive either as sheer adhesives or as portion of other products. It is therefore essential to take them into account taken how frequent and for lengthy periods of time we are subjected to these emissions. Indoor long-term exposure to VOCs can lead to the phenomenon called sick building syndrome (SBS). Formaldehyde is emitted in many construction products, including paints, adhesives, and wallboards and ceiling tiles that irritates the individuals' mucous membranes which can make him/her unpleasant. In office buildings, there are numerous other sources of VOCs, including new furniture, wall coverings, and office devices like photocopy machines, that can emit VOC particles into the atmosphere (USGBC, 2016).

There are many materials that contain VOCs, like:

- Adhesives and sealants
- Composite wood which is wood made from several materials
- Paints & coatings
- Flooring
- Furniture & furnishings
- Rooms containing equipment such as copiers

Studies have shown the concentrations of several organic substances to be 2 to 5 times greater indoors than outdoors, for which the concentrations may be up to 1000-folds in several cases, such as during and after several hours following specific operations such as paint removal. (Reference: https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality.)

A key element of IEQ is fresh air or air quality. Decent indoor air quality is achieved by the properly operating mechanical or natural ventilation systems. Opening doors and windows can naturally ventilate rooms. This is more prevalent in cooler environments in which hot moist air is rare in the summer. In mechanically ventilated areas, fans usually provide air via a series of ducts. Naturally and mechanically ventilated buildings are equipped with a mixed air flow system. The percentage of poor air is reduced through increasing the amount of fresh air entering a building. Current code minimums do not provide sufficient fresh air and they are not enough to ensure the wellbeing of the occupants – if they were, there would likely be no conditions such sick building (USGBC, 2016).

Ventilation is aimed at diluting the pollutant levels in the atmosphere. Generally, indoor air issues reduce when the amount of outdoor air increases. HVAC devices must produce appropriate quantities of outdoor air in order to dilute and potentially remove indoor contaminants. Due to the high expense of heating cold air in the winter and cooling warm air in the summer, most projects work on simply recirculating the indoor air. This leads to the accumulation of indoor contaminants. For optimum results, the system should be supplemented with continuous amounts of fresh air (USGBC, 2016).

Increased intake of outdoor air volumes will improve indoor air quality. When too little indoor air enters a house, contaminants develop, which will affect the occupants' health. Allowing fresh air in is a main factor in the reduction of indoor contaminants(USGBC, 2016).

The research aims to discover the ways to decrease the quantities of contaminants in education buildings' indoor environment, by conducting case studies at (A4 Building) in Faculty of Architecture, Design and Built Environment, Beirut Arab University, before students (Occupancies) use the various new areas, such as, Classrooms, Studios, etc.

2. METHODOLOGY

A Designer team should make sure to remove many of the contaminants and dust resulting from the construction process. Even if no products that off-gas are used for the project, something might slip through the construction process and into the air. Prior to allowing occupants in the building, it needs to be free of any contaminants.
A couple of strategies for doing this are:

- Flush out before occupancy or as maximum during occupancy but it is preferable in early stages (USGBC, 2016).
- Improving air quality testing

A construction flush-out is where outdoor air is allowed for a period of time throughout all the indoor areas. Dust and pollutants are removed from the building, the equipment and the ducts.
The old way to achieve this was called a bake-out, where the building's interior was heated. It was later found that the heating off all contaminants was not achieving any results. Contaminants and toxins were in fact releasing other contaminants that were being absorbed by fabrics and upholstery (AlSarrag, 2018).
The Main Concept of Reducing VOC levels:

- Source Control.
- Ventilation and Climate Control.

Volatile Organic Compounds are a large group of carbon based chemicals that easily evaporate at room temperature. While some VOCs come with an extremely pungent smell, others have no odor at all. According to the standards of the Total Volatile Organic Compounds, as shown in (table 1), and (table 2).

Table 1: Total Volatile Organic Compounds (TVOC) level of emissions and side effect in ug/m3
Reference: https://cfpub.epa.gov > display files >

TVOC level ug/m3	Level of Concern
Less than 300	Low
300 to 499	Accepted
499 to 999	Marginal
999 to 2999	High

Table 2: HCHO Formaldehyde level of emissions and side effect in ppm & mg/m3
Reference: Alsarrag, N.

HCHO Formaldehyde level			**Concentration-Dependent-effects**
ppm	**mg/m3**	**Level of Concern**	
0.01 – 0.125 ppm	0.061 – 0.15 mg/m3	Very Low	Odour threshold
<0.16 ppm	<0.2 mg/m3	Low	No irritation or impairment of well-being
0.16 – 0.24 ppm	0.2 – 0.3 mg/m3	Accepted	Irritation or impairment of well-being possible in case of interaction with other exposure parameters
0.24 – 1 ppm	0.3 - 1.24 mg/m3	Accepted	
1 – 2 ppm	1.24 – 2.47 mg/m3	Marginal	String in the nose, eyes, throat
2 – 3 ppm	2.47 – 3.71 mg/m3	Marginal	
3 – 4 ppm	3.71 – 4.94 mg/m3	High	Bearable for 30 minutes as max, increasing discomfort, breathlessness, lacrimation
4 – 5 ppm	4.94 – 6.18 mg/m3	High	
5 – 10 ppm	6.18 – 12.35 mg/m3	V. High	Bearable for less than 15 minutes, increasing discomfort, lacrimation, coughing.
10 – 20 ppm	12.35 – 24.7 mg/m3	Extremely High (Dangerous)	Strong lacrimation already after a few minutes of exposure (lasting for up to 1 hour after exposure), immediate breathlessness, coughing, severe burning in throat, nose and eyes
>20.24 ppm	>25 mg/m3		Headaches, other neurotoxic effects apart from headaches possible
30 ppm	37.06 mg/m3		Toxic pulmonary oedema, pneumonia, risk of death!

3. EXPERIMENTS

The Case study was the design studio in the Faculty of Architecture, Design and Built Environment, A4 Building, Debbieh Campus, Beirut Arab University, Beirut, Lebanon, as shown in figure 2 below which was built recently. Also, all furniture was all new and the capacity of each studio was 60 students and staff member, as shown in figures 3, 4, 5 below.

About painting and finishing the paint used for finishing the spaces in the case studies is Super Tinocote Paint (Tinol paint international co)

Product specification:

- Acrylic vinyl copolymer emulsion paint.
- Finishing color is eggshell, series 600 is non-toxic.
- Low odor & non-flammable.
- Free of lead, mercury, asbestos, hexavalent chromium, solvents and hazardous air pollutants.

Product Composition:

White color: - Total Solids by volume 40% - Total solids by weight 56% - Non volatile vehicle (resins) by weight 19% - Total pigments, by weight 37% - Titanium Dioxide – rutile of total pigments / gallon 1.15kgs - Density kg/L 1.35

About fittings as furniture items the material used is laminated plywood sheets.

Product specification:

- 1220mm*2440mm customizable

Product Composition:

- Material from pine, poplar.
- Glue E0, E1, E2, others.

About fittings as furniture items (chairs) the material used is thermoplastic ABS and UP leather foe upholstery.

Product specification:

- Office chair with wheels H100cm, L60cm.
- Thermoplastics scrap is easily recycled, but other materials must be disposed of carefully.

Product properties:

Strong, Light, Durable, Scratch/Chemical resistant, High surface finish.

Product Composition:

- Acrylonitrile butadiene styrene, ABS.

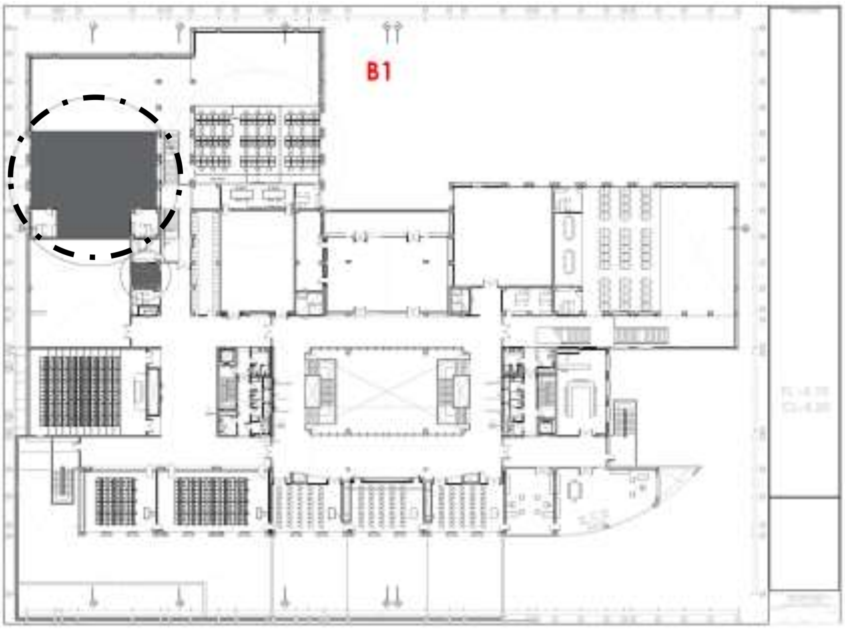


Fig.2: A4 Building - BAU – Studio 4 & office - B1
Gray shaded spaces are showing spaces used for experiments
Reference: Al-Sarrag, N

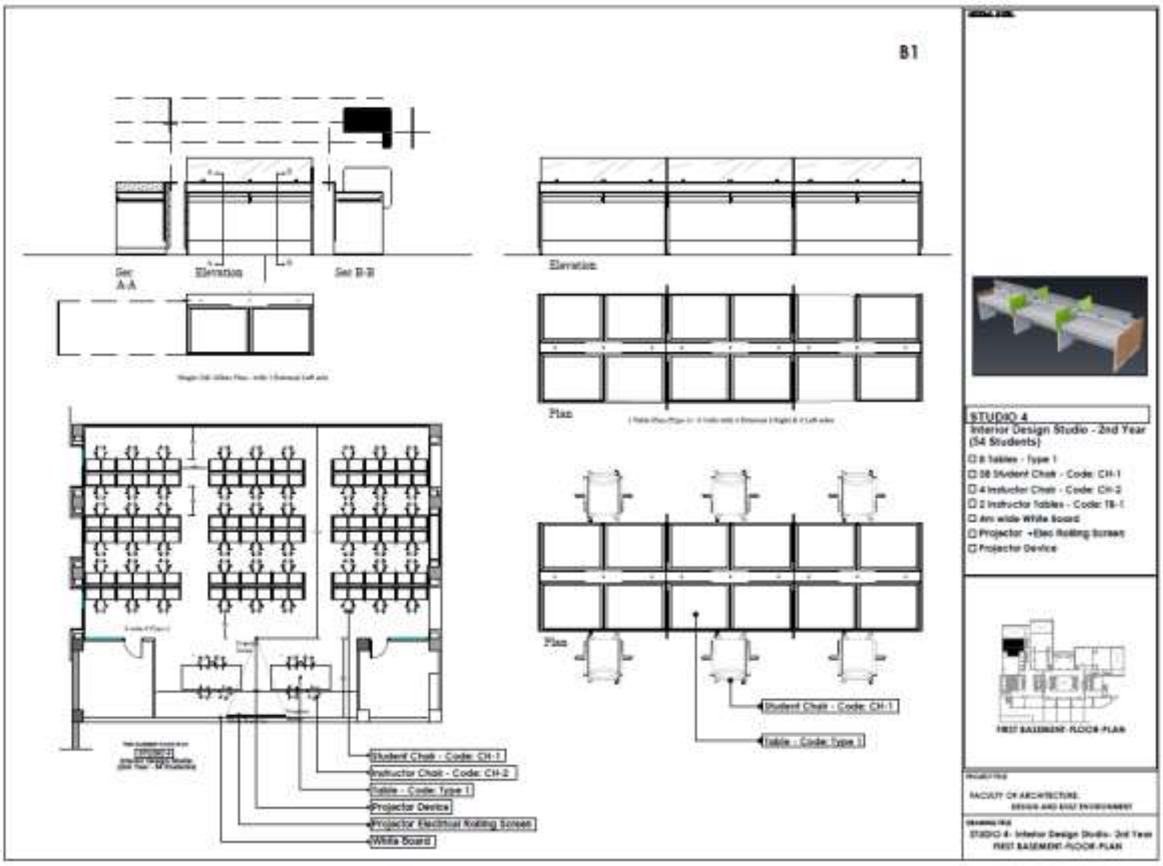


Fig.3: A4 Building - BAU - Studio 4- B1
Reference: Al-Sarrag, N.

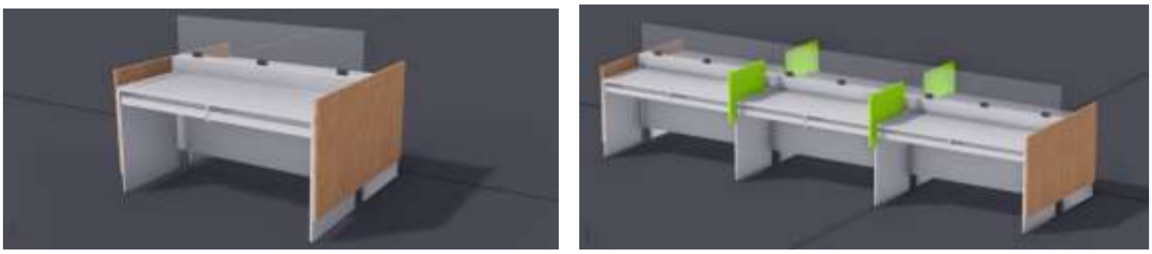


Fig.4: Desks and drawing tables and fittings in Studio 4 - B1
Reference: Al-Sarrag, N.

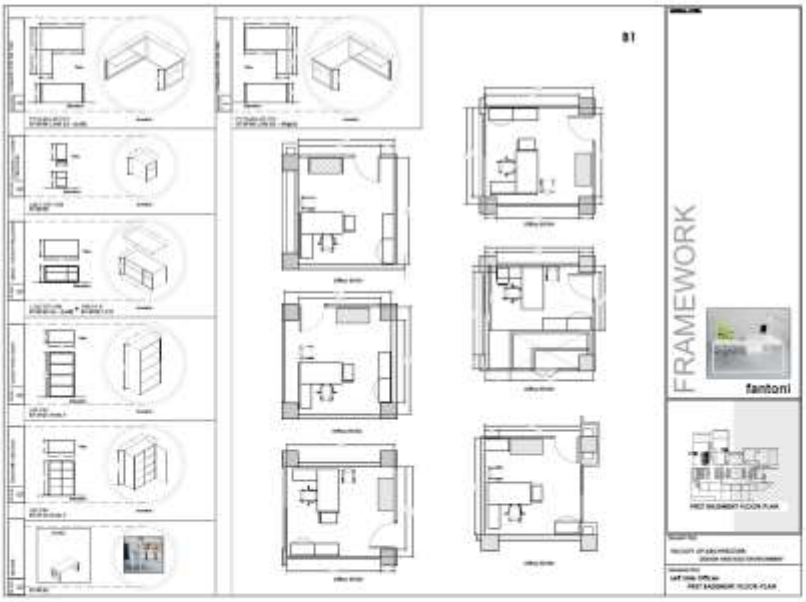


Fig.5: Office (spaces and fittings) - B1
Reference: Al-Sarrag, N.

3.1 Data Result of Experiments:

The instruments of measurement tools were EXTECH VFM200: VOC/Formaldehyde Meter as shown in figure 6. The measurement was taken in several times and several places as shown in table 3.

Fig.6: Extech VFM200: VOC/Formaldehyde Meter
Reference: http://www.extech.com/VFM200

3.1. 1. First Experiment: Detecting and measuring HCHO and TVOC concentration in air (Office Space 1)

Table 3: Measuring HCHO and TVOC (Office Space 1) Increasing room temperature
Reference: Al-Sarrag, N. using VFM200

Contaminants		**Unit PPM**	**Emission Range**	**Level of Concern**	**Space Type**	**Temp C°**	**Ventilation**	**Paint Age**	**Furniture & Appliances**
3-1	**HCHO**	0.19	0.16<0.24 ppm	Accepted	Office Space	22C° 24C°	Normal	Old <1year	Fully equipped
	TVOC	418	300<500	Accepted					

3-2	**HCHO**	0.19	0.16<0.24 ppm	Accepted	Office Space	24C° 26C°	Normal	Old <1year	Fully equipped
	TVOC	414	300<500	Accepted					
3-3	**HCHO**	0.20	0.20<0.30 ppm	Marginal	Office Space	26C° 28C°	Normal	Old <1year	Fully equipped
	TVOC	418	300<500	Accepted					
3-4	**HCHO**	0.22	0.20<0.30 ppm	Marginal	Office Space	28C° 30C°	Normal	Old <1year	Fully equipped
	TVOC	416	300<500	Accepted					

3.1. 2. Second Experiment: Detecting and measuring HCHO and TVOC concentration in air (Office Space 2)

Table 4: Measuring HCHO and TVOC (Office Space 2) Concentration/ F.time of paint
Reference: Al-Sarrag, N. using VFM200

Contaminants		**Unit PPM**	**Emission Range**	**Level of Concern**	**Space Type**	**Temp C°**	**Ventilation**	**Paint Age**	**Furniture & Appliances**
4-1	**HCHO**	2.70	2<3 ppm	Marginal	Office Space	22C° 24C°	Poor	New <1day	Empty
	TVOC	More >999	999<2999	Ext. High					
4-2	**HCHO**	2.18	2<3 ppm	Marginal	Office Space	22C° 24C°	Poor	New <2days	Empty
	TVOC	More >999	999<2999	High					
4-3	**HCHO**	1.84	1<2 ppm	Marginal	Office Space	22C° 24C°	Poor	New <3days	Empty
	TVOC	More >999	999<2999	High					
4-4	**HCHO**	1.80	1<2 ppm	Marginal	Office Space	22C° 24C°	Poor	New <4day	Empty
	TVOC	More >999	999<2999	Ext. High					
4-5	**HCHO**	1.66	1<2 ppm	Marginal	Office Space	22C° 24C°	Poor	New <5day	Empty
	TVOC	More >999	999<2999	High					
4-6	**HCHO**	1.61	1<2 ppm	Marginal	Office Space	22C° 24C°	Poor	New <6day	Empty

	TVOC	More >999	999<2999	High					
4-7	HCHO	1.56	1<2 ppm	Marginal	Office Space	22C° 24C°	Poor	New <7day	Empty
	TVOC	More >999	999<2999	High					

Table 5: Measuring HCHO and TVOC (Office Space 2) Concentration/ F.time of paint
Reference: Al-Sarrag, N. using VFM200

Contaminants		Unit PPM	Emission Range	Level of Concern	Space Type	Temp C°	Ventilation	Paint Age	Furniture & Appliances
5-1	HCHO	1.18	1<2 ppm	Marginal	Office Space	22C° 24C°	Poor	Recent >7day <2week	Empty
		1.16							
		1.12							
	TVOC	899	499<999	Marginal					
5-2	HCHO	0.47	1<2 ppm	Marginal	Office Space	22C° 24C°	Poor	Recent >3week <4week	Empty
		0.45							
	TVOC	365	299<499	Accepted					
		331							
5-3	HCHO	0.16	<0.16 ppm	Accepted	Office Space	22C° 24C°	Good	Avg> 1month	Empty
		0.15							
		0.14							
	TVOC	181	<300	Low					
		176							
		172							
5-4	HCHO	0.06	0.01<0.125 ppm	Very Low	Office Space	22C° 24C°	V.good	Average >1year	Empty
		0.03							
		0.02							
	TVOC	188	<300	Low					
		182							
		169							

3.1. 3. Third Experiment: Detecting and measuring HCHO and TVOC concentration in air (Design Studio)

Table 6: Measuring HCHO and TVOC (Design Studio 4) Improving ventilation- cfm
Reference: Al-Sarrag, N. using VFM200

Contaminants		Unit PPM	Emission Range	Level of Concern	Space Type	Temp C°	Ventilation	Paint Age	Furniture & Appliances
6-1	HCHO	0.31	0.24 – 1 ppm	Accepted	Design Studio	22C° 24C°	Medium	Average >1year	Empty
		0.30							
		0.29							
		0.28							
		0.25							
	TVOC	406	299<499	Accepted					
		414							
		420							
		417							
		444							

6-2	**HCHO**	0.31	0.24 – 1 ppm	Accepted	Design Studio	22C° 24C°	Good	Average >1year	Desks Tables Chairs
		0.30							
		0.29							
	TVOC	291	299<499	Accepted					
		292							
		291							

4. RESULTS AND DISCUSSION

The Final recommendation will be as following statements:

- Measurements and results from table 3 are showing some increasing in the emission range of HCHO (Formaldehyde) and the emission range of TVOC with using higher room temperature.(Fig.7)

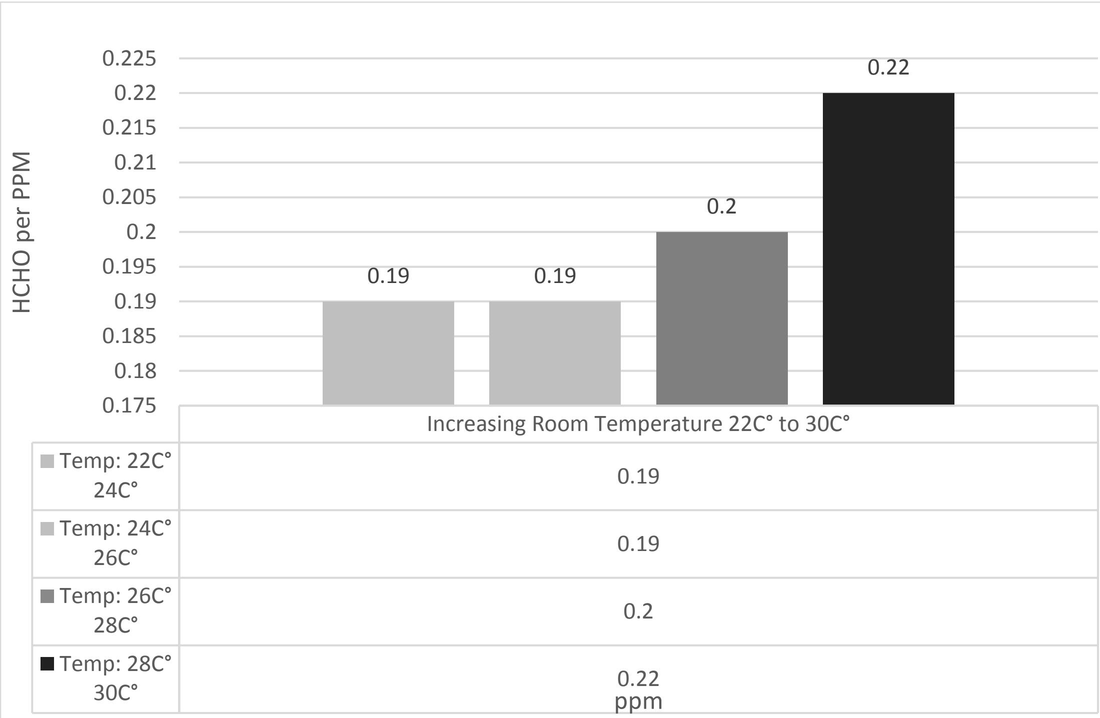
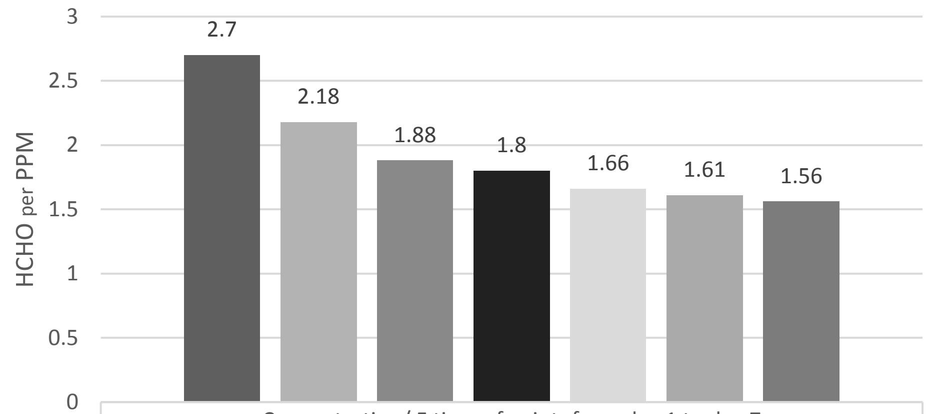


Fig.7: Increasing Room Temperature – 22C° to 30C°
Reference: Al-Sarrag, N.

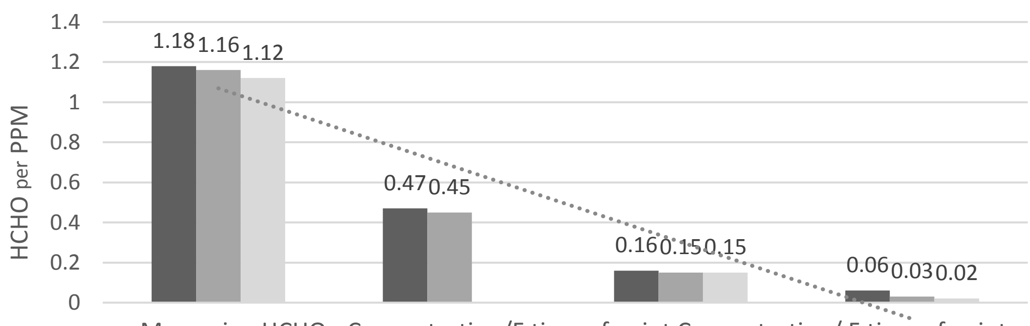
- Measurements and results from table 4 is showing very dangerous emission ranges of HCHO (Formaldehyde) and TVOC (Total volatile organic compounds) from the first day (fresh paint) and during 1 week – as shown in figure 8.



	Concentration/ F.time of paint- from day 1 to day 7
Day 1	2.7
Day 2	2.18
Day 3	1.88
Day 4	1.8
Day 5	1.66
Day 6	1.61
Day 7	1.56

ppm

Fig.8: Concentration/ F.time of paint- from day1 to day7. Reference: Al-Sarrag, N.



Measuring HCHO - Concentration/F.time of paint Concentration/ F.time of paint

	From 1week to 2weeks	From 2week to 4weeks	From #1month	From #1year
Begining	1.18	0.47	0.16	0.06
Middle	1.16	0.45	0.15	0.03
End	1.12		0.15	0.02

Fig.9: Concentration/F.time of paint Concentration/ F.time of paint – 1week to 1year
Reference: Al-Sarrag, N.

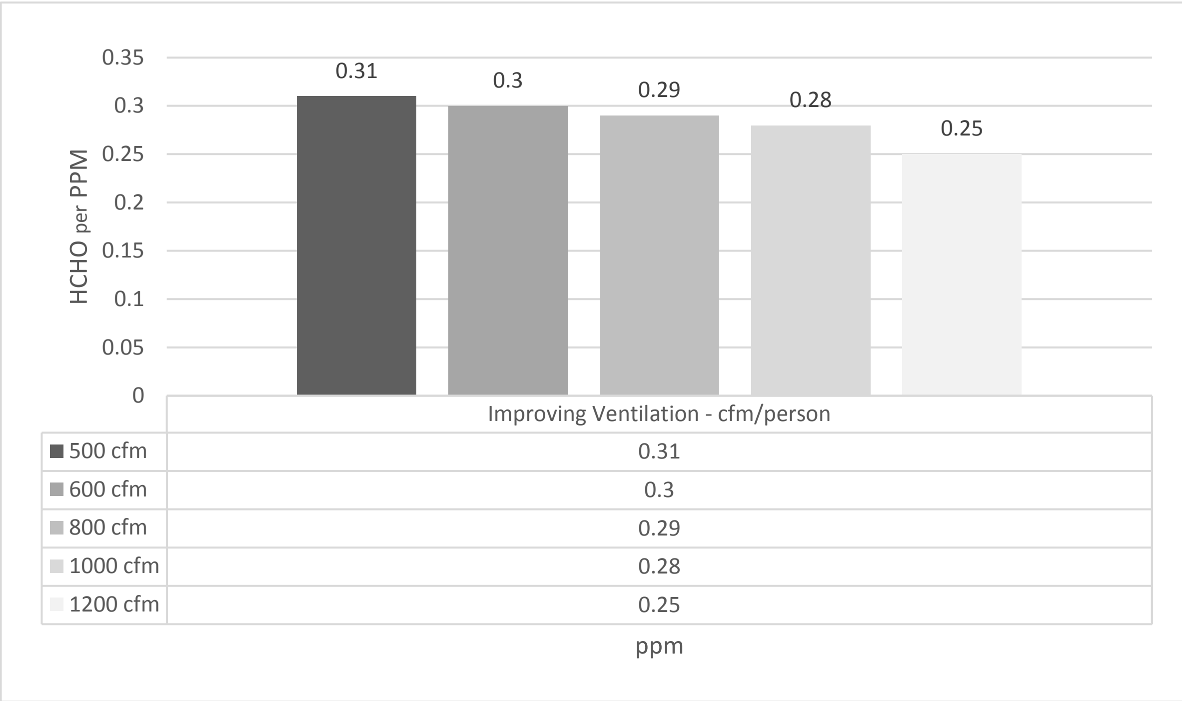


Fig.10: Improving ventilation – cfm/person (20cfm/person)
Reference: Al-Sarrag, N.

Final conclusion: The level of temperature, humidity, products & contaminations used in finishing, and space ventilation are the key role of controlling the emission of HCHO and TVOCs'.

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