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## Indoor Pollution Emissions from Building Materials; Case of Study: Gypsum Boards

Silverio Hernández Moreno\*

### ABSTRACT

This report presents an evaluation of emissions from indoor building materials that may cause health damage to the people who occupy the building, since these materials emit toxic chemicals into the air and indoor surfaces. This report presents a case study which evaluates Gypsum Boards, frequently used in the construction of dividing walls and ceilings. The experimental part of this report is based on a three-dimensional space that simulates a common room; for example, a classroom or a workstation. The indoor environmental conditions, such as ventilation, temperature, and humidity, affect chemical emissions from building materials. The technical methodology used, is based on the comparison of conventional materials and alternative materials with similar characteristics and different composition, using similar testing methods, environmental conditions, and instruments and tools. This is a very important report to understand problems related to environmental pollution, specifically of air and its effects indoors, directly on public health, and indirectly on building systems and selection of materials. The tests conclude that alternative materials (with recycled content) are better than traditional ones, because they reduce indoor pollution.

### RESUMEN

Este reporte presenta una evaluación de las emisiones de materiales de construcción, al interior de los edificios que pueden causar daño a la salud de los usuarios durante la ocupación, pues emiten sustancias tóxicas al interior de los edificios. Este reporte presenta un caso de estudio que evalúa a los tableros de yeso, frecuentemente usados en la construcción de muros divisorios y falsos plafones. La parte experimental se basa en un espacio tridimensional el cual simula un cuarto de cualquier tipo de edificación; por ejemplo: un salón de clases u oficina. Las condiciones ambientales al interior, tales como: ventilación, temperatura y humedad, afectan directamente las emisiones de sustancias químicas por los materiales de construcción. La metodología se basa en la comparación de materiales convencionales y materiales alternativos con distinta composición y similares características, en donde usamos métodos de prueba, condiciones ambientales, instrumentos y herramientas similares. Este es un estudio muy importante para entender los problemas relacionados con la contaminación ambiental, específicamente del aire y sus efectos en el interior de los edificios, y que se relaciona directamente con la salud pública e indirectamente con los sistemas constructivos y la selección de materiales en los edificios. Las pruebas concluyen que los materiales alternativos (de contenido reciclado) son mejores que los tradicionales, porque reducen la contaminación del aire al interior de los edificios.

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#### Keywords:

Air pollution; indoor emissions; Toxic chemicals; Gypsum boards; Building materials.

#### Palabras clave:

Contaminación del aire; Emisiones interiores; Sustancias tóxicas; Tableros de yeso; Materiales de construcción.

### INTRODUCTION

In Mexico, as in the world, the use of pre-manufactured materials is increasing day by day. As a consequence, the use of synthetic materials and special compounds, mainly in finishing materials for buildings, is observed. Unfortunately, this kind of materials damages the environment during its lifespan, from its extraction and manufacturing, to its application and use. Therefore, there has recently been an ecological common culture in all the branches of industry, and the construction of buildings is not an exception; then, there has been concern in knowing how much the building materials dam-

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age the environment, to draw solutions to the effect of health hazard materials in the atmosphere. In countries like USA and Canada, the use of building materials with recyclable contents is available. Besides, they are witnessing the expansion of new markets for the production of materials derived from recycling processes, as well as the reduction of waste up to a 50 % in some items and cases. They have even ended up diminishing the pollution in the interior of buildings, caused by the emission of chemical health hazard substances that materials release. The information in technical records and catalogues of products and materials, published by manufacturers, point out the existence and characteristics of such health hazard compounds, but they do not specify the very content of these chemicals that could affect the environment. Moreover, just a few of these studies have been carried in Mexico, to specify the exact content of Volatile Organic Compound (VOC). Therefore, we are very interested in knowing which products expel the lowest polluting emissions.

The testing protocol used for this report is based on the SER specifications (Special Environmental Requirements) section 01350 of CIWM (California Integral Waste Managing) Commission of Energy of California (CEC, 2001). These specifications include testing procedures of emissions, and requirements for the certification of recycled materials. This section 01350 has been republished and revised to be used in building projects in USA, in institutions such as CISC (Collaboration for the Investment of Schools Construction), who has published a manual for alternative practices (Best Practices Manual, 2002).

## REPORT OBJECTIVES

To determine the effects of materials with recycled content in relation to the quality of air at the interior of buildings, it is necessary to have the information of the emissions that each material, classified by kind and the chemical composition that emits. By knowing this information, we can also make comparison between conventional materials and building alternative, ecological or sustainable materials (these materials are from recycled composition). Therefore, it was required to perform a series of laboratory tests, such as physical and chemical tests. That is why this report is focused on building materials mentioned above, which therefore implies the report of the Quality of Air at the Interior of Building (QAIB), an takes two stages in a case of study set at a building of offices. The material subject of report is the board of gypsum used in dividing walls and pre-manufactured ceilings.

1st stage: Focused on the traditional building materials for an office.

2nd stage: Focused on the alternative building materials for an office. For this case, the recyclable content in the cardboard face is 100 %, and for the gypsum case, it is 5 % of recyclable content.

Then, our main objectives are:

- To measure the chemical emissions from traditional building products, and to compare them to their tally alternative or sustainable materials.
- To report the feasibility for the application of section 01350 as a tool to evaluate such traditional materials
- To identify the chemical substances that release these materials based on section 01350.

These ecological products, especially those with recyclable content, are highly compatible to the environment and help to control public health to the interior of buildings.

## METHODOLOGY AND DEVELOPMENT

This report is focused on a sole building product: the board of gypsum (the alternative material is the recycled board of gypsum) which is worldwide common in the market. Because of obvious reasons, we will not mention the traded mark neither the manufacturer. This kind of material is frequently used for interiors as dividing walls and ceilings.

Regarding the factors about the emissions of chemical substances from materials, we should mark a division between procedures to determine the calculation to identify the chemical substances emitted, and the kinds of chemical substances concentration that are expected to be emitted to the interior of the building after their construction or installation, as well as in the period of occupation of the building (Alevantis, L. E. *et al.*, 2002).

The use of these boards was determined as the report element in buildings for offices, since it is the most used material to subdivide architectural spaces to the interior. The emissions from pre-manufactured material will be studied in two forms: as we already mentioned at the protocol section, one is the traditional material commonly found in the national market, and the other is the kind of material that contains recycled, and which is only found in foreign markets, particularly in USA and Canada.

On the other hand, section 01350 requires a report of 96 hours of emission from materials to the interior of a room of 30 m<sup>3</sup> approximately. This measurement protocol was designed to simulate the emissions of the Volatile Organic Compound (VOC) 14 days after the installation in situ (work station of office). The measurement of the factors involved in the chemical substances emission is obtained at the end of the 96-hour test, to define and specify the chemical concentrations in the air at the interior of the room. Section 01350 enlists the concentration limits to diverse chemical substances, including the expositing levels of emission from Non Carcinogenic Materials (NCM). Besides the total number of chemical substances in this NCM list, Section 01350 requires a report of emission factors from:

- Any Emission of chemical Substances onto Polluted Air, released in the test of 96 hours will be called ESPA.
- Formaldehydes and the total emission factors of Organic Volatile Compound (OVC) to 24 h, 48 h, and 96 h.
- The 10 most abundant compounds measured outside the levels of NCM, or those belonging to ESPA.

Because the checklist of chemical substances referred in Section 01350 is rather limited, and because it represents only a small fraction of what is usually found in atmospheres of non industrial buildings (housing, offices, and commercial buildings are in the same case), we therefore used an additional indicator to obtain the quality yield from the air to the interior of the building (QAIB), to identify other chemically potential substances and variations in chemical concentrations (ASTM, 1997); such indicators include:

- Chemical substances with a well-known threshold of scent,
- A limit of partial concentration for caprolactam,
- Compounds with maximum exceeded chromatography of 5 % of the total area of Emission Testing Room (ETR).

Based on previous approaches, and in the compounds detected during the analysis of the material, a checklist of the found chemical compounds will be presented. The actions emphasized the report of the OVC which showed indices of being potential hazard for the health and impact to comfort of the building occupants to the interior of the tested room (offices). The factors of emission of OVC were used as a tool:

- A certain chemical compound with chromatography exceeded in 5 % of the ETR area,
- A variation in the emissions, according to the used analytic methods.

No method can measure by itself all the OVC that might be of interest. Moreover, the ETR area cannot be used to indicate the real effects on health damaging potency, and comfort impact to the interior.

The factors of emission were determined by laboratory tests conducted in a room or chamber that simulated the atmosphere to the interior of the building (office). These factors can be used to estimate concentrations of OVC in new constructions as well as in remodelled ones (CHSC, 2005). For the present report, the size 3,05 m X 3,66 m X 2,74 m (30,58 m<sup>3</sup>) of ETR was established, with a ventilation of 0,9 *changes of air per hour* (CAH). The following chart explains and summarizes the characteristics and dimensions of the simulation room. The building material (board of gypsum) was evaluated through a comparison of the predicted concentrations and the limits of concentrations based on approaches about environmental comfort and health criteria to the interior of the buildings.

Table 1 draws the simulation room dimensions for Emission Testing Room, where Section 01350 tests were performed, related to the limits of concentration of chemical substances emitted into the air of the interior.

Table 1.  
Dimensions for ETR chamber.

**Dimensions of Emission Testing Room for the Office (work station)**

**Dimensions of the room**

Longitude: 3,05 m; 3,66 m; height: 2,74 m

**Window and door dimensions**

Door: 0,90 m X 2,10 m

Window: 1,20 m X 1,20 m

**Factors for the calculation of air concentration**

Room Volume: 30,58 m<sup>3</sup>, minus 10 % to furniture = 27,53 m<sup>3</sup>

Room Ventilation: 0,9 changes of air per hour (cah)

**Interior Surfaces**

Floors: 11,16 m<sup>2</sup>

Roofs: 11,16 m<sup>2</sup>

Walls: 36,76 m<sup>2</sup> - 2,72 m<sup>2</sup> = 34,04 m<sup>2</sup>

Window: 1,44 m<sup>2</sup>

Door: 1,89 m<sup>2</sup>

The concentrations can be valuable to measure other chambers, commercial spaces, or another kind of buildings, to other ventilation velocities, and to other kind of material application sceneries. For example,

synthetic products for floors, furniture, painting, sealers, and other kind of architectural finishes including materials such as concrete, grout, metal, or similar to these.

## RESULTS

This section specifies the results from the two variations of material: traditional and alternative or with recycled content. The results are based on the calculation of chemical substances emissions, measured in this report. This report presents only the exceeded chemical substances (that, in this case, it is only one), according to the concentration limits in Section 01350, and the indicators for additional yield referred to the Quality of Air to the Interior of the Building (QAIB).

### Boards of gypsum, Section 01350 about the concentration limits

The traditional material, board of gypsum, did exceed the limits drawn in Section 01350. The alternative or ecological material did not.

#### Additional indicators to QAIB

Neither the traditional, nor the alternative products exceeded the additional yield indicators for QAIB.

Note: A Scanning Electron Micrograph, showed no spores of mould in any case.

Table 2 summarizes the accomplishment of Section 01350 regarding the concentration limits of tested material.

Table 2.  
According to Section 01350

Tested material	It exceeded Section 01350	It did not exceed Section 01350
Board of gypsum	Traditional material (gypsum and cardboard without recycled content)	Alternative material (recycled content of 5 % gypsum, and 100 % cardboard)

Table 3.  
Number of chemical substances that exceeded the concentration limits and other referred approaches.

Tested material	Kind of material	Concentration limits according to Section 01350	Of NCM	Of ESPA	Value for scent threshold	Partial limits of concentration
Board of gypsum	Traditional	1 (formaldehyde)	0	1 (formaldehyde)	-	-
	Alternative	0	0	0	-	-

Table 3 presents the number of chemical substances that exceeded the concentration limits towards NCM and ESPA, according to Section 01350.

It is important to mention that Table 3 specifies which chemical substance exceeds the concentration limits for the 96-hour test, which is referred to the emission of chemical compounds, formaldehyde, in this case, (section 01350 of CIWM).

Table 4 samples the results of a report of the metals which were not given off, and which do not surpass but are into the concentration limits of Section 01350. Such results were obtained from a testing analysis with Energy dispersive Spectrometry through a Scanning Electron Microscope. It is necessary to mention there were not many differences in these substances among the board of traditional gypsum and those of recycled content or alternative product. It was deduced that cellulose fibers found in traditional material, could be a sample of possible contamination in the process of production of the material. On the other hand, rakes or particles of mold spores were not found in none of both materials (neither in the one recycled nor in the traditional one).

Table 4.  
Other substances such as metals and fibers were found in rakes of the concentration limit testing for the board of gypsum which do not exceed section 01350

Test on the board of gypsum	Found metals	Other particles
Testing of analysis through spectroscopy of dispersed energy	Strontium, copper, zirconium, zinc, manganese, uranium, chromium, nickel, tin, lead, and cobalt	Cellulose fibers

Table 5 presents the emission factors in  $\mu\text{g}/\text{m}^2\text{h}$  at 96 hours, of the released chemical substances that compose the boards of gypsum (traditional and alternative). Notice that substances such as acetone and nonanale are also emitted, which do not exceed the limits of the section 01350.

Figure 1 shows a photo taken with an electronic microscope, from a sample of material of gypsum board, where particles of strontium were found (as the one shining in the figure at the right top) and although they were

Table 5.  
Emission factors in  $\mu\text{g}/\text{m}^2 \text{ hr}$  of chemical substances emitted by both types of gypsum board at 96 h.

Emitted Chemical substances	Traditional gypsum Board	Alternative gypsum Board
Acetone	35	0
Nonanale <sup>1</sup>	2,7	2,1
Formaldehyde	19 (it exceeds the norm)	0

<sup>1</sup> It is an aldehyde that typically represented a significant fraction of the VOC reactivity defined as  $k(\text{OH})[\text{VOC}]$  in atmosphere. However, this information is misleading with regard to the impact of these aldehydes on ozone formation, as their oxidation can represent a significant  $\text{NO}_x$  sink. Nonanale is hazard only in combination with others substances, such as: nonanale + OH reaction. The OH + nonanale reaction rate constant was determined via the relative rate technique and found to be  $3.6 (+/- 0.7) \times 10^{-11} \text{ cm}^3 \text{ molecule}^{-1} \text{ s}^{-1}$ . Under conditions of high  $[\text{NO}_2]/[\text{NO}]$ , we determined that 50 +/- 6% of OH-nonanale reaction occurs via abstraction of the aldehydic H-atom through measurement of the peroxyxynonyl nitrate yield.

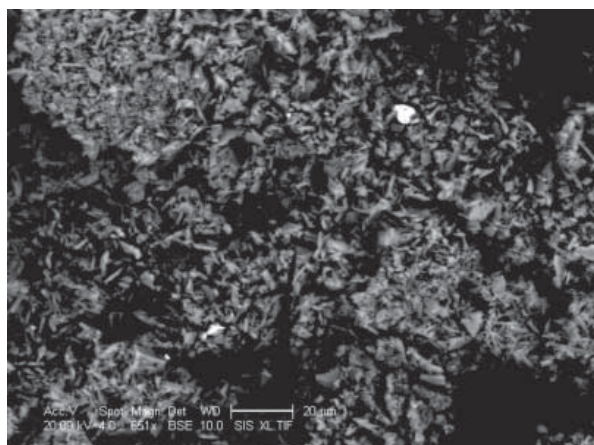


Figure 1. Strontium (metal) particle absorbed in the gypsum of the case of study (This photo was taken from the Scanning Electron Microscope of the Laboratory of Technology; Architecture College, UCLA).

absorbed in the material, these do not represent any hazard, since they do not exceed the concentration limits of the section 01350 for these type of particles and chemical substances.

### LIMITATIONS

In this report, technical specifications of the tested products (boards of gypsum) are not mentioned, neither the manufacturers nor the brands, by obvious reasons; the results should not be used to recommend the selection of materials and products in any way.

The results also depend on the measures of the room or chamber where are carried out the tests, on the interior surfaces, on the laboratory equipment used, on the particular methods employed, on the variations when some chemical substances are manifested, on the employed experimental analysis testing, on type of finishing materials employed on the surfaces and furniture, as well as on ventilation, temperature, humidity, product type, brands and origin.

### CONCLUSIONS

The calculation of the concentrations of air carried out in the room or chamber to simulate a typical work (office) station, with standard measures, derived from factors of emissions such as dimensions, surfaces, speed of wind, temperature, humidity, etc., they were carried out to complement tests of laboratory on air concentrations based on the section 01350 of California Integral Waste Managing, (CEC, 2001), we achieved the following conclusions:

- The alternative board of gypsum or sustainable type, made with recyclable materials, emits smaller emissions of pollutants than the traditional board of gypsum.
- The traditional board of gypsum emits chemical health hazard substances onto the environment and the interior of buildings, and particularly, it exceeds the air concentration limits of section 01350 for one substance, formaldehyde.
- The manufacturers should improve their products to minimize the emissions, mainly in substances such as: formaldehydes, naphtalenes and acetaldehydes.
- Better results are obtained if the same analysis methods are applied for both products (boards of gypsum, such as traditional as alternative).
- The tests should be, however, analyzed by several qualified laboratories to find better results.
- The tests could vary depending on the physical conditions of the environment and chemical substances of the products.
- The emissions of the materials could vary according to the period of material production date until the execution of the test. Also, from their packing process and stored process; for this case of study, the products were kept along 10 days of the 96 h testing however, small differences between one and each other products were found.

- Section 01350 of the norm of CIWM (California Integral Waste Managing) could also be used in Mexico, to report these kinds of emissions in similar materials, since these products are manufactured under the same international normativity of quality and certification.
- This report does not research criteria about materials sustainability, just the recycled content in the alternative materials and the emissions of VOC in the installed materials and tested materials; for example, this report does not report emissions generated during the production of materials, the transporting to the selling point, its packing process, or the microbial factor of contamination.

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