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# ROOF BASED ON LOW ENVIRONMENTAL IMPACT CONCRETE VAULT

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**Abstract:** This research shows the results of a study carried out to determine the equivalent CO2 emissions generated by the construction of a roof or mezzanine based on a reinforced concrete vault with ribs and metal formwork finished with a plasterboard panel and recycling material. The data obtained were compared with other industrialized construction systems, such as solid slab, joist and vault, as well as panel with a polystyrene core traditionally used in the construction of roofs and mezzanine slabs for housing in the state of Oaxaca, Mexico. The data was obtained through the use of a spreadsheet that quantifies the emission of CO2 equivalent by the consumption of construction materials, the operating personnel in charge of its execution and the machinery that intervenes in its realization, taking as reference the construction systems, yields and dosages used in this entity. The results revealed that the proposed roof based on concrete vault generates a lower environmental impact because its construction allows to achieve reductions of 6 to 50% of equivalent CO2 emissions with respect to other construction systems evaluated.
**Keywords:** Ecological footprint, CO2 emission, Concrete cover.

## INTRODUCTION

### GOALS

Determine the equivalent CO2 emissions generated by the construction of a roof or mezzanine based on a concrete vault and compare these data with those generated by other industrialized construction systems such as solid slab, joist and vault, as well as panel with a concrete core. expanded polystyrene traditionally used in the construction of roofs and mezzanine slabs for housing in the state of Oaxaca.

## METHOD DESCRIPTION

To quantify greenhouse gas emissions, specifically carbon dioxide CO2 equivalent, a quantitative analysis was carried out through a book in the Excel program that, through the use of spreadsheets in the form of tables of CO2 emission data produced by materials, operating personnel and machinery, applied to the consumption generated by each construction system, allowed us to determine its environmental impact. In this program, several variables related to the construction processes and materials used in each of the evaluated construction systems were considered. To generate the database, information published in other investigations was considered, where the CO2 emissions emitted in the manufacture of various construction materials were determined experimentally. Additionally, an analysis was carried out on the carbon dioxide emissions generated by the use of machinery and by its operating personnel, which was included in the program's database, this being one of the contributions of this research to area of study, since such information is limited in the literature on the subject.

In order to have a basis for comparison, the dimensions of a living space to be resolved with the different construction systems were determined, applying it to the project of a room with measurements in meters of 4.30 x 3.30 to axes with a slope of 13%, as shown. shows in picture 1.

Subsequently, the most used roof construction systems in buildings intended for housing in the city of Oaxaca de Juárez were considered, the construction systems to be analyzed being:

1. Cover based on reinforced concrete slab with main reinforcement in two directions.
2. Roofs based on joists and vaults.
3. Covers based on panels with an expanded polystyrene core.

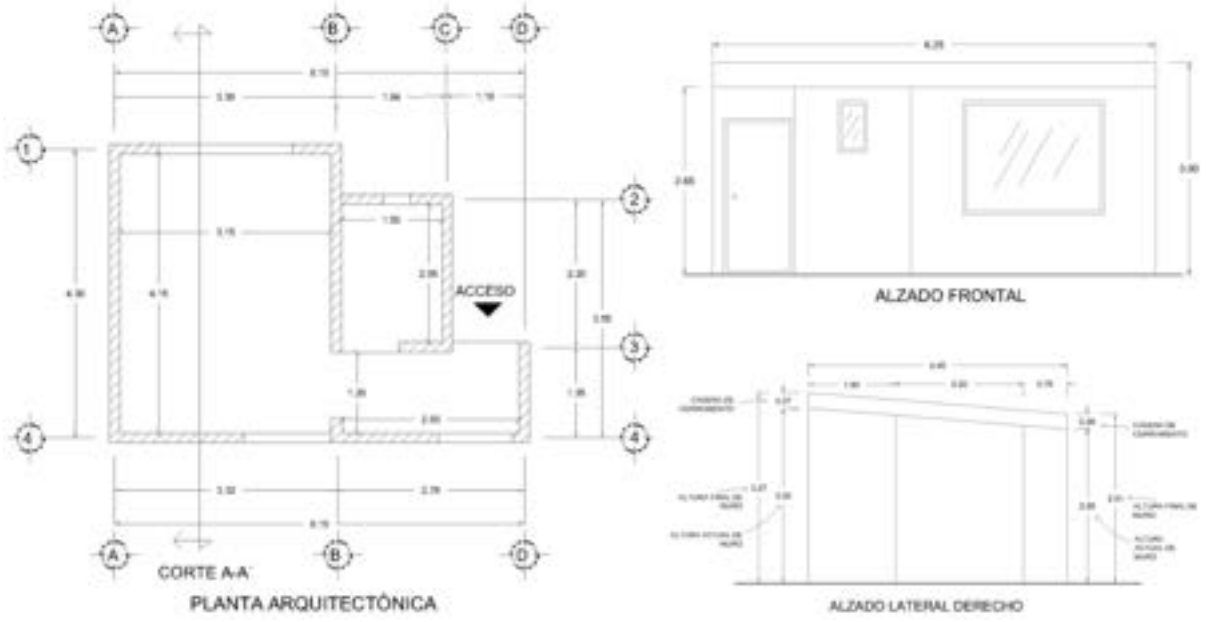


Image 1.- Project to be developed without scale.

4. Cover based on reinforced concrete vault with ribs.

The dimensioning of the different roof systems considered the following structural calculation variables:

1. The Complementary Technical Standards for the Design and Construction of Concrete Structures of the Federal District were used as a reference, in accordance with what is marked in article 198 of the Construction Regulations of the State of Oaxaca (RCEO) which, in its second paragraph, says verbatim:

> *AS LONG AS THE SECRETARY DOES NOT ISSUE SUCH STANDARDS, WHAT IS SPECIFIED IN THIS ARTICLE SHALL BE GOVERNED BY THE COMPLEMENTARY TECHNICAL STANDARDS OF THE DEPARTMENT OF THE FEDERAL DISTRICT OR BY ANY OTHER ORGANISM RECOGNIZED BY THE SECRETARY.*

2. The calculation method used for the roof structure based on a concrete vault is based on the method for calculating structures at failure limit states described in section 2 of the aforementioned Technical Standards.

3. A maximum live load of 40 kg/m2 corresponding to roofs and flat roofs with a slope greater than 5% was considered according to article 229 of the RCEO.

4. In the dead load applied to the concrete slab and the concrete vault system, a load increase of 40 kg/m2 was considered in accordance with the provisions of article 228 of the RCEO.

5. Regarding the compressive strength of the concrete used in the structures, f'c=200 kg/cm2 was taken as it is the minimum strength allowed according to section 4.3. of the NTCDF-concrete, in addition to being the most commonly obtained in the dosage of concrete made directly on site. Considering a ¾" coarse aggregate (19 mm gravel).

6. The reinforcement steel considered to withstand the structural tension is grade 42, having fy= 4200 kg/cm2, since it is the resistance of the rods currently sold on the market.

Each of the roof systems analyzed had their own considerations in their dimensioning as described:

**Reinforced concrete slab** - A thickness of 10 cm was considered. With a reinforcement of 3/8 rods with separation every 20 cm. Placing sticks on the continuous edges where the rods go at the same separation. The formwork used is based on 3rd grade pine wood and grade 42 steel, being the most commercial. The reinforcement is left over with respect to the calculation; however, it is the separation normally used in the region.

- **Joist and Vault System**. - An open-core system with 15-cm-high mortar vaults is considered, since it is the most widely used and commercialized system today. Considering a 6x6-10/10 electrowelded mesh reinforcement applicable to a roof with a 4 cm thick compression layer based on concrete f'c= 200 kg/cm2 with T.M.A.G. of ¾".
- **System with expanded polystyrene core panel.**. - The Panel W® brand system is considered in the Panel W modality 3" slab with expanded polystyrene core with a 4 cm thick compression layer with compressive strength f'c=200 kg/cm2 with reinforcement of 1 3/8" rod per rib supporting a maximum span of 3.6 m and a factored ultimate load of 498 kg/m2 on roofs with a slope greater than 5%, according to the product supplier's technical data sheet.
- **Propuesta de Cubierta a base de bóveda de concreto armado con nervaduras**. - The vaults are formed by concrete ribs separated by 93 cm, with axes with a width of 5" (12.5 cm) and a cant of 26 cm reinforced with a 3/8" rod in the lower and upper bed, and Wire rod stirrups with a branch every 11 cm, with a 4 cm thick vault reinforced with 6x6-10/10 electro-welded mesh as distribution steel or by volumetric changes. The formwork is based on smooth 20-gauge sheet metal, supported on 5"x5" purlin stringers every 93 cm that also function as contact formwork and 4"x4" purlin props spaced every 1.50 m.

For the calculation of the reinforcement of the roof based on a concrete vault, an ultimate load of 463 kg/m2 was considered. Taking into account a load factor of 1.4, the maximum moment obtained by estimating supports without restrictions is 574 kg/m and a critical shear force of 627 kg, for which a reinforcement of 1 3/8" rod was considered, which It gives us a resistant moment of 617 kg/m higher than requested. And with wire rod stirrups from one branch, a separation of 38 cm is obtained, choosing to use the maximum separation which, in this case, is 11 cm. Details of the cover are attached in figure 2.

In order to take advantage of the cavity generated by the vault, it was filled with PET bottles for thermal and acoustic insulation, and a ½" thick sheetrock false ceiling was placed, fastened with 3/16" rods, screwed to each 30 cm, joining the leaves with Redimix and Perfacinta brand tablaroca®. See figure 3.

## CRITERIA FOR THE ANALYSIS OF THE EMISSION OF CO2 FOR EACH CONSTRUCTION SYSTEM

- To determine the amount of CO2 equivalent pollutant emitted in the production of the materials, the values proposed by two main sources of information were considered: the Ministry of Agriculture, Food and Environment of Spain, presented in May 2014, and the Environmental Information of Products and Systems of the Institute of Construction Technology of Catalonia (ITeC), Spain, presented in March 2017. Likewise, to determine the emission of CO2 produced in obtaining wood for formwork in construction, the

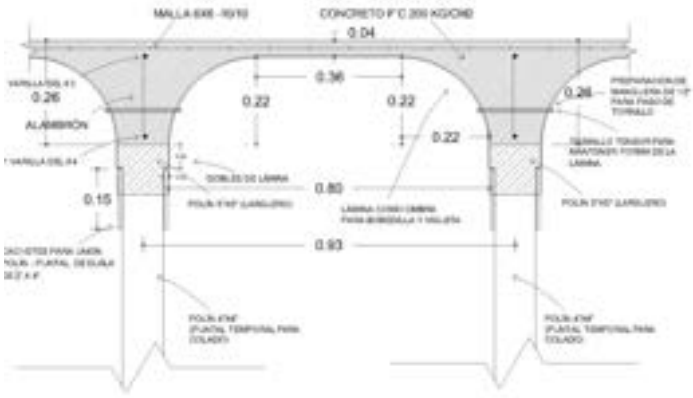


Figure 2. Detail of the roof based on a reinforced concrete vault.

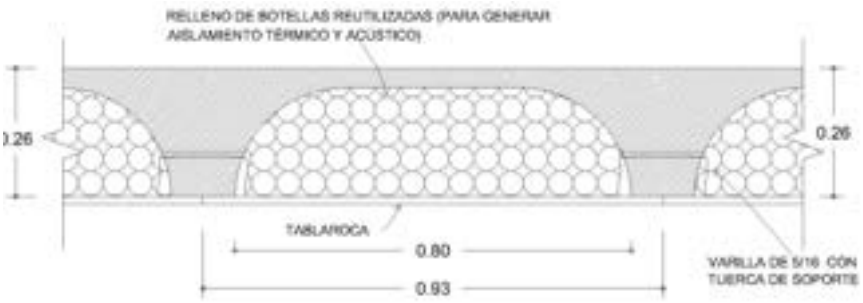


Figure 3. Detail of the false sheetrock ceiling.

study carried out by Alejandro Carazo, Manager of Térmica AFAP S.A., which appears in his article "Basic figures of the relationship WOOD-Carbon Fixation-Atmospheric CO2", published in March 2016. In all of them it was necessary to convert the measurement of kg of material per kg of CO2 emitted in its production, by that of the Analysis Unit used in the construction usually used, as shown in table 1. In some cases In those, in which the material is made up of two materials (such as the case of the panel with an expanded polystyrene core or the precast open-core joist used in the joist and vault system), the CO2 emission was determined based on the percentage of participation of the materials that compose it according to its weight.

- In order to take into account the personnel involved in carrying out the construction processes of a work, the emission of 8.81 kg of CO2 equivalent per day worked was taken, grouping them according to the nature of their work, also considering the participation of the middle management that coordinates the work in a proportion of 1/10 of Working day per worker, integrating groups as shown in table 2.
- In the construction processes, minor equipment was used which, in its operation, emits pollutants as a result of fuel consumption, the use of lubricating oil and tires. The contaminant that was produced in the production of the equipment was also considered in proportion to its useful life in hours and the maintenance it receives. The results

| Complete description | Unit | CO2 emission x unit |
|---|---|---|
| Water | m3 | 0.800 |
| Annealed wire | Kg | 3.400 |
| Wire rod | Kg | 2.800 |
| River sand | m3 | 48.000 |
| 1 1/2" x 3 1/2" 3a. | P.T. | 2.360 |
| Vault of 16 perlate and 70 long | Pza. | 3.960 |
| Normal gray cement type I | Tn | 320.000 |
| Normal gray cement type I | Tn | 410.000 |
| Chamfer | ml | 0.050 |
| Nail | Kg | 2.800 |
| Diesel | Lt | 2.700 |
| 3/4" x 4" staves of 3a. | P.T. | 2.360 |
| Sorted river gravel | m3 | 81.000 |
| 20 gauge smooth sheet | m2 | 32.670 |
| Electro-welded mesh 6x6-10/10 | m2 | 2.740 |
| Zig-zag type mesh, 16.50 cm wide x 2.44 m long, formed with highly polished steel. resistencia de fy = 5,000 kg/cm2 | tira | 1.170 |
| Standard 12.7 mm thick gypsum panel, 1.22 x 2.44 m sheet. | Hoja | 5.710 |
| W panel type L-PS-3 with 3" (7.5 cm) thick polyurethane and 14-gauge mesh of fy = 5,000kg/cm2 de 3.05 x 1.02 m. | Pza. | 89.900 |
| 3 1/2" x 3 1/2" idler | P.T. | 2.360 |
| 1 1/2" x 12" x 8 1/4' plank of 3a. | P.T. | 2.360 |
| 1/4 x 8" Nut Bolt | Pza. | 0.420 |
| Pine plywood of 16 mm of 3a. | Hoja | 1.450 |
| Varilla corrugada del # 3 (3/8") | Tn | 2800.000 |
| 3/16" x 10" rod w/rubber boot | Pza. | 0.070 |
| Precast joist 14-36, 6.0 m long | m | 7.210 |

Table 1.

| Complete description | Unit | CO2 emission per day |
|---|---|---|
| Group 1 bricklayer + 1 pawn + 2/10 corporal | Working day | 19.382 |
| Group 1 bricklayer + 2 pawns + 3/10 corporal | Working day | 29.073 |
| Group 1 mason + 5 pawns + 6/10 corporal | Working day | 58.146 |
| Group 1 blackwork carpenter + 1 assistant "b" + 2/10 corporal | Working day | 19.382 |
| Group 1 official setter + 1 assistant "b" + 2/10 corporal | Working day | 19.382 |
| Group 1 ironworker of black work + 1 assistant "b" + 2/10 corporal | Working day | 19.382 |
| Group 1 mixer operator + 6 pawns + 7/10 corporal | Working day | 67.837 |

Table 2. List of work groups with equivalent amount of CO2 emitted per work day.

of this analysis are shown in Table 3.

- In the construction process of the different systems analyzed, auxiliary composition analyzes were determined, such as concrete, formwork and steel fittings that make up the total contaminants per unit analyzed. Their issued values are presented in Table 4.

## FINAL COMMENTS

Due to the fact that the proposal for a roof based on a concrete vault is a contribution to solve this type of system, a detailed analysis of the composition elements that allowed determining the amount of pollutants emitted per m2 is presented, as shown in Table 6.

| Complete description | Unit | CO2 Emission x Hour |
|---|---|---|
| Single bag concrete mixer 8 h.p. (320 L). | H/M | 5.617 |
| Anchor concrete vibrator | H/M | 2.472 |

Table 3. List of minor construction equipment used with equivalent amount of CO2 emitted per hour of operation.

| Complete description | Unit | CO2 emission x Unit |
|---|---|---|
| trestle scaffold | Uso | 2.730 |
| Apparent formwork in concrete vaults with metal formwork | m2 | 9.990 |
| Common formwork in flat slabs | m2 | 18.020 |
| Casting of concrete made on site in beams and slabs | m3 | 10.030 |
| Production of trestle scaffolding | Pza. | 65.550 |
| Manufacture and casting of concrete f'c=200 kg/cm2 made on site in beams and slabs | m3 | 258.500 |
| Enabled and reinforced with steel in structures number 2 (1/4") | Tn | 3230.380 |
| Enabled and armed with steel in structures number 3 (3/8") | Tn | 3202.070 |
| Enabled and armed with electro-welded mesh 6x6-10/10 in slabs | m2 | 3.140 |
| Cement-sand mortar 1:4 | m3 | 206.260 |
| Cement-lime hydra-sand mortar 1:1:6 | m3 | 206.130 |

Table 4. Auxiliary construction analyzes used with equivalent amount of CO2 emitted per unit.

| Complete description | Unit | Issue x Unit | / | Quantity | Total |
|---|---|---|---|---|---|
| Manufacture and casting of concrete f'c=200 kg/cm2 made on site in beams and slabs | m3 | 258.5000 | * | 0.1000 | 25.850 |
| Enabling and steel reinforcement in number 3 structures (3/8") | Tn | 3,202.0700 | * | 0.0011 | 3.522 |
| Enabling and steel reinforcement in number 2 structures 2 (1/4") | Tn | 3,230.3800 | * | 0.0007 | 2.390 |
| Apparent formwork in concrete vaults with metal formwork | m2 | 9.9900 | * | 1.0000 | 9.990 |
| Enabled and armed with 6x6-10/10 electro-welded mesh in slabs | m2 | 3.1400 | * | 1.0000 | 3.140 |
| | **Emission of CO2 eq. x concept** | | | | **44.892** |

Table 6. Analysis of equivalent CO2 emitted by the slab-based roofing system based on concrete vaults with ribs every 94 cm, 12x25 reinforced with 1 1/2" and 1 3/8" rods. stirrups from no. 2 of a branch every 11 cm with electro-welded mesh 6x6-10/10, Concrete f'c=200 kg/cm2 made on site.

## SUMMARY OF RESULTS

As a final result of the analysis of the amount of equivalent C2 emitted in its construction, the result shown in table 7 is obtained. It must be mentioned that these values include those related to flattening and false ceiling placed in the different systems.

We can observe in table 7 that the cover based on Panel W is the one with the highest emission of pollutants (82.5 kg of CO2/m2); the concrete vault slab has a saving of 42% in pollutants (47.9 kg of CO2/m2) and the other two systems only 10%.

Analyzing by type of input, the four systems behave in a similar way; that is, materials represent 90% of the total, while operators only 9% and minor equipment only 1%.

Analyzing the participating materials in more detail, it was found that the proposal presented for using metal formwork in a vaulted shape requires very little wood. Likewise, when a raised support section is generated, it requires little reinforcing steel and a small amount of concrete compared to the solid slab systems (which require 12 kg/m2 more for the steel) and the Joist and Vault system (which requires 35 kg/m2). kg of CO2/m2 more due to the cement), not to mention Panel W that requires 30kg of CO2/m2 more due to the expanded polystyrene. Table 8 is attached showing these results.

| Roof system | CO2xM2 emission | % relative to the maximum |
|---|---|---|
| *Solid concrete slab f´c=200kg/cm2 T.M.A.G. 3/4" 10 cm thick, reinforced with 3/8 rod every 18 cm in both directions, common finish, includes flattening in a 2.5 cm thick mix ceiling with a fine finish.* | 71.822 | 87% |
| Cover based on a 20 cm thick joist and vault with a 4 cm thick layer of concrete f'c=200 kg/cm2 and 6x6-10/10 electro-welded mesh and mortar vaults. Includes flattened 2.5 cm thick mix ceiling with fine finish. | 75.308 | 91% |
| Slab based on a 3" W panel (Slab panel) with a 4 cm compression layer and reinforced with 1 3/8" rod in each rib. Includes flattened 2.5 cm mix ceiling. thick fine finish. | 82.500 | 100% |
| Slab based on concrete vaults with ribs every 94 cm of 12x25 reinforced with 1 1/2" rods and 1 3/8" rods, stirrups no. 2 of a branch every 11 cm reinforced with electro-welded mesh 6x6-10/10, Concrete f'c=200 kg/cm2 made on site. Includes drywall false ceiling fastened with a 5/16" rod every 30 cm. | 47.942 | 58% |

Table 7. Equivalent CO2 emission for the construction of one m2 of roof, according to type.

| Material involved | Solid slab | Joist and Bov. | Pannel w | Conclusion Vault |
|---|---|---|---|---|
| STEEL | 18.50 | 5.50 | 12.10 | 6.80 |
| CEMENT | 19.00 | 50.60 | 14.90 | 15.70 |
| FORMING | 13.30 | 3.50 | 5.50 | 6.70 |
| STONES | 9.70 | 6.90 | 7.30 | 8.10 |
| POLYSTYRENE | 0.00 | 0.00 | 30.10 | 0.00 |
| OTHER MATERIALS | 3.90 | 1.40 | 2.60 | 6.90 |
| **Total of materials** | **64.40** | **67.90** | **72.50** | **44.20** |

Table 8. Analysis of the total CO2 emitted x m2 of roof in the main materials used in the construction systems analyzed.

## CONCLUSIONS

Based on the results obtained in this investigation, the following conclusions can be established:

- The CO2 emissions for each construction system analyzed, in which the concrete vault-based system is the one that involved the least pollutant emission in its construction (47.9 kg of CO2 x m2).
- The database that was generated from information published in research, where the greenhouse gases emitted in the manufacture of various construction materials were determined experimentally, made it possible to accurately quantify the equivalent CO2 emissions for each system of construction, type of input, be it material, operating personnel or minor equipment. The participation of each type of input was also precisely determined, noting that cement, expanded polystyrene, reinforcing steel and falsework (wood) are the materials used with the highest degree of pollution emitted in their production and construction.
- This research shows us that, although it is known that the aforementioned materials generate a high degree of pollutants, we dare to ensure that they can continue to be used, as long as their consumption is rationalized, as in the proposal presented for a vault that takes advantage of your best behavior.

## RECOMMENDATIONS

The proposal presented has as a limitation the use of a cant greater than the others, this is 27 cm with respect to the others of 13, 22 and 14 cm respectively, affecting when increasing the height in multi-level buildings, so it is It is recommended to carry out this type of analysis in other construction systems used in roofs and mezzanines.

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