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# SUSTAINABLE PRODUCTION AND MANAGEMENT OF AN INDUSTRIALIZED HOUSE

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The *PRO.CRE.AR. Bicentenario* (Argentine Bicentennial Single-Family Housing Credit Program) implemented between 2012 and 2015 approximately, included a model of wooden houses, thus enhancing in Argentina the opportunity to have a house built with industrialized wooden elements. The paper compares at a conceptual level the construction of the same house (similar to the prototype named "Maderera") as a traditional building, i.e., with brick masonry and reinforced concrete, and instead with industrialized wood construction as funded by the PRO.CRE.AR program: the comparison focuses on the amount of $CO_2$ incorporated in the two constructive solutions. Alongside this assessment, conducted on the basis of estimated quantities of materials and data found in the literature, the paper examines the amount of $CO_2$ not produced over the lifetime of the house when photovoltaic elements and solar panels are possibly adopted for local energy production and then discusses the positive impact of any energy storage systems. The results regarding the building energy demand and the $CO_2$ saved support the choice of building industrialization for the wood supply chain, propose additional options for the deployment of wood construction, and evaluate the impact of home PV & solar panels for sustainability and integration into the technological system.

*Keywords*: Photovoltaic, Wooden building, Solar DHW production, Sustainable home.

## 1 INTRODUCTION

The "PRO.CRE.AR. BICENTENARIO" (aka Argentine Bicentennial Credit Program for Single Family Housing), opened in 2015 the possibility to finance a first model of a pre-fabricated wood house named Maderera of 80.88 $m^2$ area. This single-story dry-built house has 3 bedrooms, two bathrooms, and a living room with kitchenette in a flexible layout with large windows and a sheet metal roof with small pitches.

The introduction of wood and drywall construction technologies should have a positive effect on the housing market due to shorter lead times, more competitive construction costs and, most importantly, positive impact on the environment due to its capability to retain carbon dioxide. The Argentine Ministry of Agriculture, Livestock and Fisheries, claim a 216 $m^2$ wooden construction retains 28.5 tons of $CO_2$ from the atmosphere that is about the emissions of a small gasoline car for seven years (Ministerio de Agricultura 2014). In fact, this *Maderera* model uses wood for only 50 percent of its volume, and the purpose of this work is to investigate what its footprint is on greenhouse gas production, both in the construction phase and over its lifetime.

## 2 THE «MADERERA» MODEL

The building (Figure 1) is a four-room single-family house with a compact floor plan suitable for a maximum of 5 people (Minoli 2015). The net interior height is 2.60 m while the total exterior height is 3.71 m. The house has a living room (2.77 × 5.60 m) of 15.5 m$^2$, a kitchenette and a dining area of about 8.1 m$^2$ (3 × 2.70 m); the rest of the residence houses three bedrooms and two windowless bathrooms (measuring 2.8 and 2.5 m$^2$, respectively), one of which is equipped also with a bath tub. The master bedroom measures 3.35 × 3.37 m for 11.3 m$^2$, the other two bedrooms are 8.7 m$^2$ (2.78 × 3.20 m) and 8 m$^2$ (2.53 × 3.20). The entire sleeping area is disengaged via a short corridor of about 5 m$^2$. The house plan is structured to have windows on only two opposite fronts (street side and courtyard side), so that it can be aggregated by flanking to form entire blocks.

Figure 1. The *Maderera* house: general north view (left) and plan (right).

Following the unanimous demand of all the timber business operators, who asked the technical bodies for equal treatment with the rest of the construction materials accepted in housing plans, the research group investigated the carbon footprint of both the proposed timber technological system (Maderera) and a brick masonry one. In the Table 1 the building envelope for the *Maderera* timber solution is compared with the traditional brick masonry technique. The ground floor (concrete slab) and all double-glazed windows (wood frame) are the same in both cases, so they have no influence on the model comparison.

Table 1. Building envelope specification and thermal performances.

| | **external wall** | | **roof** | |
|---|---|---|---|---|
| | *timber house* | *traditional house* | *timber house* | *traditional house* |
| *stratigraphy (out to in)* | painted wood (50mm)<br>cavity (30mm)<br>cement panel (45mm)<br>glass wool (50mm)<br>chipboard panels (10mm)<br>exp'd polystyrene (36mm)<br>plasterboard (12.5mm) | exterior plaster (15mm)<br>glass wool (80mm)<br>perforated bricks (180mm)<br>cement plaster (10mm)<br>gypsum finishing (5mm) | trapezoidal metal roof (1mm thick)<br>vented interspace (30mm)<br>glass wool (80mm)<br>cavity (60mm)<br>plasterboard (12.5mm) | bitumen felt shingles (5mm)<br>glass wool (80mm)<br>one-way perforated-brick slab (160+40mm)<br>cement plaster (10mm)<br>gypsum finishing (5mm) |
| *overall thickness* | 235mm | 290mm | 184mm | 300mm |
| *U-value (energy)* | 0.288 W/m$^2$·K | 0.290 W/m$^2$·K | 0.320 W/m$^2$·K | 0.325 W/m$^2$·K |
| *summer decrement factor* | 0.410 | 0.241 | 0.989 | 0.227 |
| *summer time-lag* | −8.115 h | −9.387 h | −1.051 h | −8.436 h |
| *periodical thermal transmittance* | 0.118 W/m$^2$·K | 0.07 W/m$^2$·K | 0.316 W/m$^2$·K | 0.074 W/m$^2$·K |

The winter peak load is estimated to be 3,613 W for the *Maderera* wood construction, and 3,675 W for masonry construction: these are therefore essentially comparable performances, as is the case in summer, where the cooling peak load is 5,606 W for the wood house and 5,528 W for the traditional building. The *Maderera* house performs slightly better in winter than in summer, as expected from the envelope performance in Table 1, where the summer time-lag and decrement factor are instead favored by the high mass of the traditional house.

## 3 THE CONSTRUCTION PHASE: CARBON FOOTPRINT COMPARISON

In order to compare the $CO_2$ incorporated in the two different technological solutions, the quantities of each material used in the two cases were calculated and the $CO_2$ contents were based on the average values in the database of the software by One Click LCA Ltd. (2023), considering the production phase only, as defined "A1-3" by the standard UNI EN ISO 15978:2011, which includes the $CO_2$ equivalent emission produced by the procurement of raw materials, transportation and the production process of the building material. On site transportation was instead neglected, because the place where the construction will be being not predictable, and also the contribution of furniture and plant systems was not considered because they are not dependent from the chosen building technology (wood or masonry).

The *Maderera* global warming power (GWP) for the roof and the exterior wall is expressed in kg of $CO_2$ equivalent, originating from the items listed in Table 2, while the items for the traditional building are listed in Table 3: ground slab and windows are not included because they are the same in both options, as explained above.

Table 2. GWP estimation for the *Maderera* building.

| envelope | layer | quantity | GWP specific | estimated GWP |
|---|---|---|---|---|
| external wall | plasterboard (9 kg/$m^2$) | 318.85 $m^2$ | 0.325 kg $CO_{2\,eq}$ / kg | 932.636 kg $CO_{2\,eq}$ |
| | painted wood | 3,099.82 kg | 0.678 kg $CO_{2\,eq}$ / kg | 2,101.678 kg $CO_{2\,eq}$ |
| | cement panels | 5,511.49 kg | 1.151 kg $CO_{2\,eq}$ / kg | 6,343.725 kg $CO_{2\,eq}$ |
| | chipboards panels | 636.20 kg | 0.668 kg $CO_{2\,eq}$ / kg | 424.982 kg $CO_{2\,eq}$ |
| | glass wool (50 kg/$m^3$) | 344.42 kg | 68.039 kg $CO_{2\,eq}$ / $m^3$ | 468.680 kg $CO_{2\,eq}$ |
| | expanded polystyrene (30 kg/$m^3$) | 137.77 $m^2$ | 103.667 kg $CO_{2\,eq}$ / $m^3$ | 514.159 kg $CO_{2\,eq}$ |
| roof | plasterboard | 916.84 kg | 0.325 kg $CO_{2\,eq}$ / kg | 297.973 kg $CO_{2\,eq}$ |
| | glass wool (50 kg/$m^3$) | 335.84 kg | 68.039 kg $CO_{2\,eq}$ / $m^3$ | 457.004 kg $CO_{2\,eq}$ |
| | trapezoidal metal roof (5 kg/$m^2$) | 83.96 $m^2$ | 3.465 kg $CO_{2\,eq}$ / kg | 1,454.607 kg $CO_{2\,eq}$ |
| | | | **total** | **12,995.444 kg $CO_{2\,eq}$** |

Table 3. GWP estimation for the traditional (masonry) building.

| envelope | layer | quantity | GWP specific | estimated GWP |
|---|---|---|---|---|
| external wall | gypsum finishing (1300 kg/$m^3$) | 144.26 $m^2$ | 0.642 kg $CO_{2\,eq}$ / kg | 601.997 kg $CO_{2\,eq}$ |
| | cement plaster (1800 kg/$m^3$) | 2,596.68 kg | 0.578 kg $CO_{2\,eq}$ / kg | 1,500.881 kg $CO_{2\,eq}$ |
| | exterior plaster (1200 kg/$m^3$) | 144.26 $m^2$ | 0.527 kg $CO_{2\,eq}$ / kg | 1,185.990 kg $CO_{2\,eq}$ |
| | perforated bricks masonry (144 kg/$m^2$) | 20,773.44 kg | 0.278 kg $CO_{2\,eq}$ / kg | 5,775.016 kg $CO_{2\,eq}$ |
| | glass wool (50 kg/$m^3$) | 144.26 $m^2$ | 68.039 kg $CO_{2\,eq}$ / $m^3$ | 621.931 kg $CO_{2\,eq}$ |
| roof | bitumen felt shingles (5 mm thick) | 112 $m^2$ | 0.922 kg $CO_{2\,eq}$ / kg | 619.584 kg $CO_{2\,eq}$ |
| | glass wool (50 kg/$m^3$) | 344.96 kg | 68.039 kg $CO_{2\,eq}$ / $m^3$ | 469.415 kg $CO_{2\,eq}$ |
| | one-way perforated-brick slab, complex | 88 $m^2$ | 66.733 kg $CO_{2\,eq}$ / $m^2$ | 5,872.504 kg $CO_{2\,eq}$ |
| | gypsum finishing (1300 kg/$m^3$) | 86.24 $m^2$ | 0.642 kg $CO_{2\,eq}$ / kg | 359.880 kg $CO_{2\,eq}$ |
| | cement plaster (1800 kg/$m^3$) | 1,552.32 kg | 0.578 kg $CO_{2\,eq}$ / kg | 897.241 kg $CO_{2\,eq}$ |
| | | | **total** | **17,904.439 kg $CO_{2\,eq}$** |

All specific GWP values in Tables 2 and 3 refer to the 80th percentile of global production of that component as recorded in global databases.

Looking at the difference between the two values of total GWP estimated in Tables 1 and 2, the global warming power differs between the *Maredera* and the traditional building by about 5 tons of $CO_2$ equivalent, or 37.5 percent less, in favor of the wooden house. In both cases, the major contributors to the GWP are the brick and concrete components, the latter also implemented in the wooden house to give it a favorable thermal mass (inertia), which is useful in slowing down and dampening the internal temperature peak during hot days.

Even taking into account the variability in GWP data of individual elements due to the different use of recycled material or the transportation impact, the lower effect on $CO_2$ production of the wooden house is evident: more than one-third of the $CO_2$ is avoided, which demonstrates the environmental need to spread wood building systems from renewable forests. In addition, the wooden house is partially dismountable and reusable elsewhere.

## 4 CARBON FOOTPRINT IN THE BUILDING SERVICE LIFE

Both buildings were modeled and their energy requirements were rated according to the UNI EN ISO 13790:2008 (as implemented in EC700 Software that complies also with UNI-TS 1300) (ISO/TC 163 Technical Committee 2008).

After assessing the impact on greenhouse gas production to build the two dwellings previously described, the research also integrated an estimate of the $CO_2$ produced over the service life of the buildings, with reference to winter heating, summer cooling and domestic hot water production, i.e., the three services that are directly integrated into the construction of the building. Both building systems perform essentially the same (the gap between the energy requirements of wood construction and traditional construction is about 0.5 percent, however within ± 5 percent representing the accuracy of modeling). For this reason, although the in-service performance data are listed only for the wood building system, which has the lowest environmental impact, they are essentially the same as those for the traditional masonry house: this can be useful in assessing the benefits of GWP containment strategies e.g., with respect to existing residential neighborhoods.

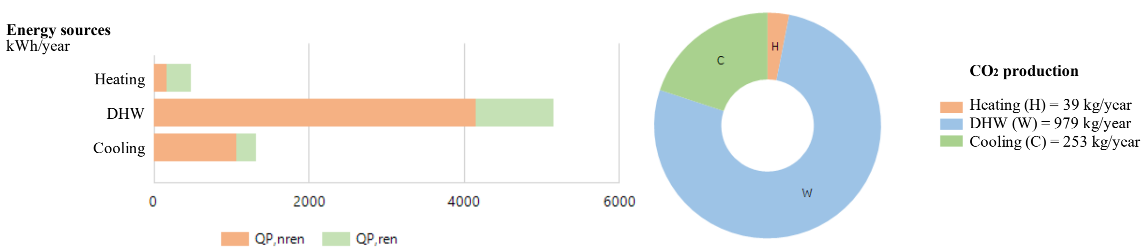



Figure 2. Wooden house, situation A (electric DHW production): non-renewable [QP nren] and renewable [QP ren] energy loads (left) and $CO_2$ production (right) per year.

The energy behavior of *Maderera* was simulated in Buenos Aires neighborhood, with the North façade (entrance) to the street in four different situations: no renewable energy sources (situation A), thermal solar panels for DHW (situation B), photovoltaic only (situation C) and thermal and photovoltaic panels (situation D), adapting to Latin America the EC700 Software (Edilclima 2023).

First, the model has no local renewable energy source, that is, no solar photovoltaic or thermal panels, while heating and cooling are provided by an electric heat pump system. The annual energy demand and $CO_2$ production are shown in Figure 2: the main $CO_2$ contribution comes from domestic hot water production with a simple 100-liter electrically heated cylinder (situation A).

The total electricity demand is 2,763 kWh per year (2,129 kWh for DHW; 550 kWh for cooling; 84 kWh for heating: the very low impact of the heating is due to the good winter performance of the building envelope and the high solar gain through the windows, assuming that in winter all shutters and blinds are fully open). The global $CO_2$ production is estimated of about 1 ton per year.

Situation B involves replacing the electric water heater with a 300-liter volume solar water heater equipped with 2.5 m$^2$ flat solar panels. One third of the tank can be heated electrically to overcome periods of bad weather. In this case, the total electricity demand decreases by about 56 percent to 1,210 kWh per year (576 kWh for DHW; 550 kWh for cooling and 84 kWh for heating remain identical). The annual energy demand and $CO_2$ production are shown in Figure 3.

It is evident how the adoption of solar hot water panels significantly increases the use of renewable energy in domestic hot water, reducing its impact on the overall energy balance. The $CO_2$ from domestic hot water production becomes similar to the one of the cooling services and the global production of $CO_2$ drops to about 0,55 tons per year.

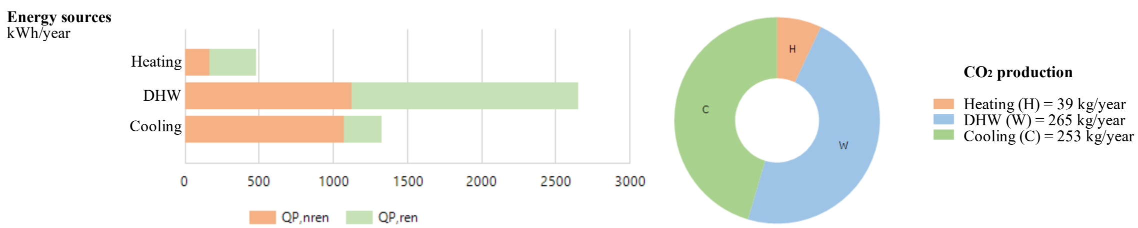
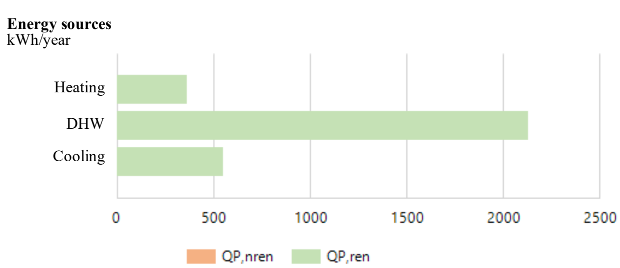



Figure 3. Wooden house, situation B (solar/electric DHW production): non-renewable [QP nren] and renewable [QP ren] energy loads (left) and $CO_2$ production (right) per year.

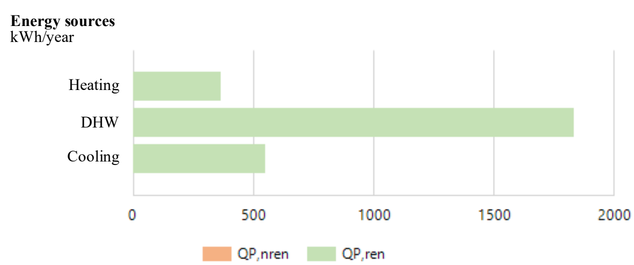



| Month | PV production [kWh] | Heating [kWh] | DHW [kWh] | Cooling [kWh] | PV surplus [kWh] |
|---|---|---|---|---|---|
| July | 269 | 26 | 181 | 0 | 62 |
| August | 269 | 27 | 163 | 0 | 79 |
| September | 358 | 0 | 181 | 0 | 177 |
| October | 420 | 0 | 175 | 0 | 245 |
| November | 500 | 0 | 181 | 0 | 319 |
| December | 538 | 0 | 175 | 99 | 264 |
| January | 480 | 0 | 181 | 117 | 182 |
| February | 525 | 0 | 181 | 131 | 213 |
| March | 415 | 0 | 175 | 101 | 140 |
| April | 378 | 0 | 181 | 102 | 95 |
| May | 284 | 0 | 175 | 0 | 109 |
| June | 234 | 31 | 181 | 0 | 21 |
| **Total** | **4670** | **84** | **2130** | **550** | **1906** |

Figure 4. Wooden house, situation C (electric DHW production and PV 1.2 kWp): non-renewable [QP nren] and renewable [QP ren] energy loads (left) and photovoltaic usage (right).

Situation C involves a different approach to sustainable building with the adoption of photovoltaic cells on the roof. In this case, 6 photovoltaic panels of 210 Wp each are installed on the roof, with a total peak power of 1.23 kW and a footprint of about 8 sq. m. The results are remarkable (Figure 4): the energy needs of the house are totally met by renewables, while using an electrically heated tank for domestic hot water. No $CO_2$ is produced, and a total of 1907 kWh is available for home use or to be shared in an energy community. La *Maderera* becomes a sustainable home with little expense (the additional cost is about US$ 2,000).

Situation D adds the same solar DHW heater to situation C as situation B, combining the use of PV (1.23 kWp) and solar thermal. The results are even better (Figure 5): the energy for DHW production is reduced to 1,833 kWh and no $CO_2$ is produced because all energy needs (DHW, cooling, heating) are again totally met by renewables, but here the energy available for home use or to be shared in an energy community increases to 3,460 kWh. On the other hand, the additional cost rises to about US$ 3,500.




| Month | PV production [kWh] | Heating [kWh] | DHW [kWh] | Cooling [kWh] | PV surplus [kWh] |
|---|---|---|---|---|---|
| July | 269 | 26 | 93 | 0 | 150 |
| August | 269 | 27 | 74 | 0 | 169 |
| September | 358 | 0 | 58 | 0 | 300 |
| October | 420 | 0 | 34 | 0 | 385 |
| November | 500 | 0 | 16 | 0 | 484 |
| December | 538 | 0 | 14 | 99 | 425 |
| January | 480 | 0 | 16 | 117 | 347 |
| February | 525 | 0 | 14 | 131 | 380 |
| March | 415 | 0 | 29 | 101 | 286 |
| April | 378 | 0 | 45 | 102 | 231 |
| May | 284 | 0 | 77 | 0 | 208 |
| June | 234 | 31 | 107 | 0 | 95 |
| **Total** | **4670** | **84** | **577** | **550** | **3460** |

Figure 5. Wooden house, situation D (solar/electric DHW production and PV 1.2 kWp): non-renewable [QP nren] and renewable [QP ren] energy loads (left) and photovoltaic usage (right).

## 5 CONCLUSION

The research has shown how the case study has a lower $CO_2$ impact than traditional buildings (1/3 saved) because it is made from wood. This single-family house also saves energy during its life. The deployment of this technology contributes at least to the achievement of two of the United Nations Sustainable Development Goals: "climate action" (due to low energy demand) and "no poverty" (responding to the cost-of-living crisis). In addition, the implementation of solar thermal panels can dramatically reduce the energy impact of hot water production, and similarly, the simple addition of a small photovoltaic system (1.2 kW peak) can contribute to two other UN SDGs: "affordable and clean energy" and "sustainable city and communities", because HVAC and domestic hot water systems operate with zero carbon emissions, with no air pollution, since they are powered by renewable sources that can be shared through energy communities.

Industrialized production of such building components through the sustainable wood supply chain allows for good repeatability of the home's energy performance and promotes innovation and sustainability in the industry as well.

### Acknowledgments

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