

DARNA: Saudi Recycled, Sustainable House - Innovation Challenge

Team 28 : Mohammed Alkohlani-ISE , Abdullah AlMansour-ISE , Mohammed AlGarni-EE, Nawaf AlSubki-ME, Abdulaziz AlShehri-ME

Coach : Dr. Muhammad Emzir



Introduction

Elevator Pitch

For families looking for a sustainable and comfortable home, DARNA offers an innovative off-grid solution using local materials, water recycling and solar energy to cut waste and boost energy efficiency. Unlike traditional homes, DARNA integrates smart technologies that lower environmental impact while maintaining cost-effectiveness, aligning with Vision 2030's goals.

Constraints

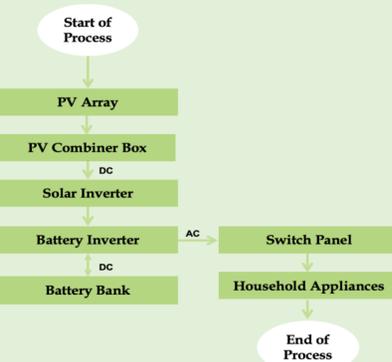
- Follow all Saudi Government Building Regulations
- Follow all other Saudi codes, specifications, and regulations pertinent to your home
- Budget less than 10,000 SAR to build:
 - 1:10 - 1:100 scaled model of home
 - a single, full size, room of the home
- Made from 90% materials (by weight) sourced from Saudi Arabia

Specifications

- Cost of full-size home 5,000 SAR/m²
- Every 1L of used water generates 0.05 SAR of income or offset income
- Full-size home recovers purchase price in 20 years
- Power system capable of delivering:
 - a. 500W (220VAC) during daylight hours
 - b. 300W (220VAC) during nighttime
- Wall/Roof/Floor R-value = 20
- Capable of withstanding wind speeds of 30 m/s

Methods & Techniques

Energy System Design



- **Estimated Daily Load:** 36.796 kWh/day.
- **Inverter Efficiency:** Combined efficiency of 94.38%.
- **Energy from Battery:** Adjusted for inverter losses: 38.987 kWh.
- **Battery Efficiency:** BYD BatteryBox with 96.5% round-trip efficiency.
- **Energy from Solar Array:** Adjusted for battery efficiency: 40.40 kWh.

Water System & Income Generation

Objective Function:

$$\text{Minimize: } Q_{total\ water} = Ws(1 - Rs \cdot xs) + Ww(1 - Rw \cdot xw) + Wk(1 - Rk \cdot xk) + Wh(1 - Rh \cdot xh)$$

Subject To:

$$\begin{aligned} &\text{Water Consumption Target: } Q_{total\ water} \leq 900 \text{ liters/day} \\ &\text{Energy Consumption Constraint: } 2/1000 \cdot Q_{total\ water} \cdot 0.264127 \leq 0.475 \text{ kWh/day} \\ &\text{Binary Constraints: } xs, xw, xk, xh \in \{0,1\} \end{aligned}$$

- This reduced water consumption from 260 L/day/person to 173 L/day/person which enabled significant savings through water recycling. The system processes 284 liters/day, equivalent to 8,520 liters/month. With an average cost of treated water at 0.677 SAR/liter, the monthly savings are:

$$8,520 \times 0.677 = 5,768.04 \text{ SAR/month.}$$

For six people, the savings per liter is:

$$\text{Savings per Liter} = 5,768.04173 \times 6 \times 30 = 0.185 \text{ SAR/liter}$$

Cooling System & R-Value > 20



Objective Function:

$$\text{Min Cooling load} = \left(\frac{Aw\Delta T}{Rw}, i\right) \cdot xw, i + \left(\frac{Ag\Delta T}{Rg}, i\right) \cdot xg, i + \left(\frac{Ar\Delta T}{Rr}, i\right) \cdot xr, i + \left(\frac{Af\Delta T}{Rf}, i\right) \cdot xf, i$$

Subject To:

$$\begin{aligned} &\text{Material Selection: } \sum ixw, i = 1, \sum ixg, i = 1, \sum ixr, i = 1, \sum ix f, i = 1 \\ &\text{R - Value Constraints: } Rw, i \cdot xw, i \geq 20, Rg, i \cdot xg, i \geq 20, Rr, i \cdot xr, i \geq 20, Rf, i \cdot xf, i \geq 20 \\ &\text{Energy Consumption Constraint: } Q_{total\ cool} \cdot PAC \cdot 24 \leq 62,400 \text{ Wh/day} \end{aligned}$$

- This led to choose:
 - The wall consists of AAC blocks with an R-value of 15 + The wall will be coated with mineral wool insulation, which has an R-value of 10 for 7.5 cm thickness. The total = 25 R-value
 - The Roof of DARNA will be coated with Extruded polystyrene (XPS) Board, which has an R-value of 30 for a 15 cm thickness.
 - The Floor of DARNA will be coated with Extruded polystyrene (XPS) Board, which has an R-value of 25 for a 12.5 cm thickness.

Withstanding wind speed of 30 m/s

Structural Solutions:

- **Walls:** Incorporating AAC blocks with additional coated materials for enhanced insulation and durability.
- **Roof, Floor, Glass:** Utilizing a coated material to optimize energy efficiency and structural strength.

- **Wind Pressure:** $P = 0.5 \times \rho \times V^2, 0.5 \times 1.225 \times (30)^2 = 551.25 \text{ Pa}$
- **Wind Load:** $F = P \times A, 551.25 \text{ Pa} \times 556 \text{ m}^2 = 306,495 \text{ N}$



Results & Validation

Power System

- Each solar panel produces approximately 2.27 kWh/day based on a 550W panel with ~6 hours of peak sunlight (data from Global Solar Atlas).
- Total daily energy requirement: 40.4 kWh/day.
- Accounting for system and PV inefficiencies, the number of panels required is calculated as: $n_p = \frac{E_{total\ Epanel}}{2.27} = 17.79$
- **Number of Solar Panels Needed ≥ 18 panels.**

Withstanding wind speed of 30 m/s

- Wind Load: 306,495 N for a wind speed of 30 m/s.
- AAC Block Strength: With a compressive strength of about more than 1 MPa, AAC blocks can easily withstand the wind pressure.

Income Offset

- We saved 0.185 Sar / Liter for six people
- We were able to achieve the specification that says 1L of used water generates > 0.05 SAR of income or offset income

Full House Cost & Recovery Within Less than 20 Years

- Full house cost is going to be in a range of 1,836,244 - 1,935,244 SAR
- Recovery is between 17 -18 years which achieves the specification of recovery within less than 20 years

Conclusion

DARNA project highlights sustainable housing in Saudi Arabia's desert climate, combining renewable energy, water recycling, efficient cooling systems, and wind resistance up to 30 m/s. Multidisciplinary efforts achieved reduced energy and water use, presenting a resilient and eco-friendly housing model.

