Rendered view of Oasis Abode by CEPT's Team Kill Bill

Designing a Benchmark Net Zero Single Family House in Jaipur

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Introduction

Team 'Kill Bill' from CEPT University, Ahmedabad won the 1st place in the Urban Single-family category in the Race to Zero (RTZ), an international design competition conducted annually by the U.S. Department of Energy. The winning entry was the design of a net zero energy and zero water discharge home in Jaipur, with air quality prescribed by World Health Organization (WHO) despite Jaipur's ambient air pollution. The jury hailed this entry for excelling in all ten evaluation criteria of the competition. The team presented their work at National Renewable Energy Laboratory (NREL), Golden, Colorado, USA in the final round of the competition.

For the 2017 competition, 45 collegiate teams designed net zero energy homes for locations of their choice, and a panel of industry experts evaluated the designs on different criteria that included performance, aesthetics, constructability and affordability.

The CEPT University Team

Team Kill Bill was led by students in the M. Tech. program in Building Energy Performance (BEP) at the Faculty of Technology, with additional members from the faculties of architecture and planning. While the core team's expertise is in the area of energy efficient and green buildings, they also have design expertise in mechanical and civil engineering, architecture and interior design. Some of the team members also have professional work experience.

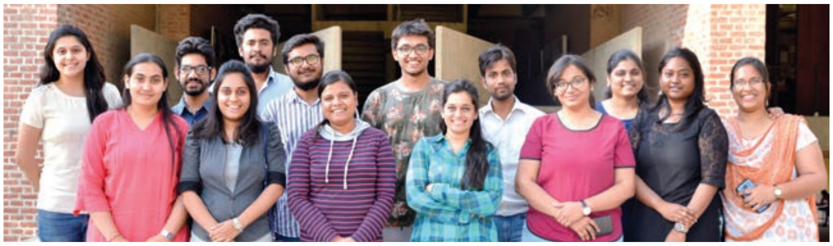

Photo 1: Team Kill Bill, from left (back row) Vasudha Sunger, Arihant Jain, Nikhilesh Singh Bist, Arjun Desai, Akash Ghadiyali, Sahil Priyadarshi, Archanaa M, (front row) Kurva Dhonde, Pooja Mundhe, Vertika Srivastav, Aakanksha Khare, Mansi Parikh, Sandhiya Jayakumar, Shravya Reddy and (absent) Sumit Rawat

Project Background

Figure 1: Geographic location of Jaipur and Phoenix

The site is in Jaipur, and was chosen for its resemblance to the climate in Phoenix, Arizona, U.S.A. to keep it familiar for the competition jury. Both cities fall in Climate Zone 2B of the International Energy Conservation Code (IECC).

A net-zero residence fits perfectly in the Indian context given shortage of grid-supplied energy evidenced by frequent brownouts in most cities in the country. India is a signatory to the Paris Climate Change Accord and intends to produce 40% of all electricity from non-fossil sources. The high cost of land, depleting groundwater levels and degraded air quality make this design problem very relevant to India as well as other tropical regions around the world that are experiencing rapid economic growth.

The team researched the ambient air quality of Jaipur. The data provided by Central Pollution Control Board and National Ambient Air Quality Standard (NAAQS) showed that the concentrations of PM2.5 and PM10 are at critical levels as per the World Health Organization (WHO) and NAAQ standards. See *Figure 2*.

The team modified the US based competition requirements with a combination of US and Indian standards to keep the design relevant for India while ensuring adequate compliance and rigor for the US-based jury. Thus, requirements from US DOE Zero Energy Home, IECC 2015, SVA-GRIHA green building rating system, India's National Building Code, ASHRAE Standard 62.1 for Indoor Air Quality, BEE's Star Rating program and Central Government Rebate Program for On-site Renewable Energy became the bases of design. The project also utilizes the rebates provided by the Ministry of New and Renewable Energy (MNRE), Government of India, which offers 30% rebate on photovoltaic systems for residential projects.

Team Kill Bill set the following goals:

- Improved energy performance with energy use intensity (EUI or EPI) less than 20 $kWh/m^2/year$ without compromising occupant comfort. A typical house in this climate (business-as-usual) consumes 50 $kWh/m^2/year$.
- On-site renewable energy to match the consumption.
- Zero water discharge by capturing storm water and wastewater for reuse on site, and to recharge sub-surface ground water.
- A debt to income ratio of 40% or less, for a higher middle-class family.
- Durable construction technology with life expectancy of 75 years.
- A design compliant with *Vaastu* principles to increase the market appeal.
- Meet WHO standards for PM2.5 and PM10 with an annual mean of 10 $\mu g/m^3$ and 20 $\mu g/m^3$ respectively for indoor air for occupants.

Project Design

Approach

The design approach of Oasis Abode is rooted in the responsibility the team feels towards the natural environment. It is also a move against the trend of isolating the building interior from the outdoors that has come about in India as a necessary response to increased levels of pollution and urban heat island effect. The innovation lies in a design response that integrates learning from historical buildings that use local materials, passive design and the latest technologies to provide a healthier indoor environment while minimizing energy use. The design approach brings together user preferences in the form of their behaviour, comfort and lifestyle aspirations. It has architectural integrity in the form of design rigor, detailing and material selection, and engineering integrity in the form of high performance, affordability and cutting edge technologies.

The students took up roles such as architect, cost estimator, energy consultant, MEP consultant, etc. and followed a real-life integrated design process by conducting design charades, agreeing upon goals, developing options, evaluating them for performance and detailing out the preferred ones. Performance analysis preceded design decisions at every stage.

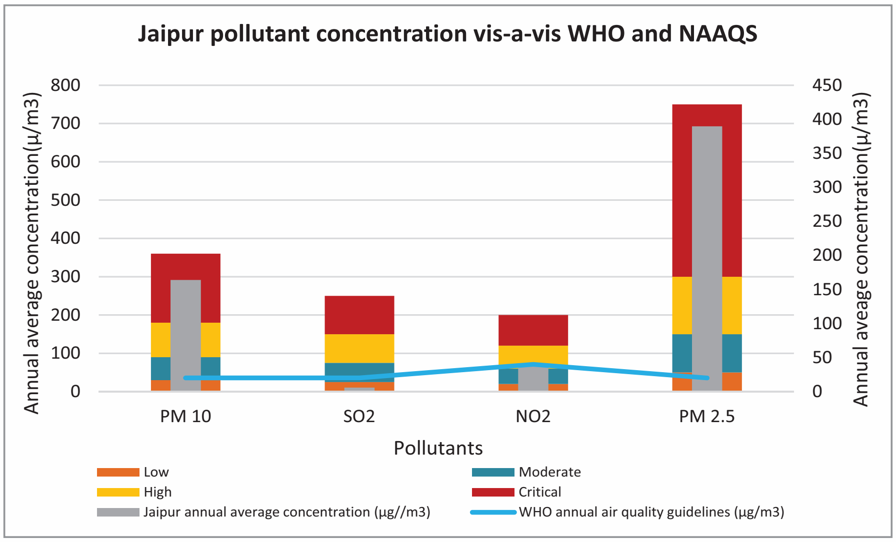

Figure 2: Pollutant concentration in Jaipur ambient air

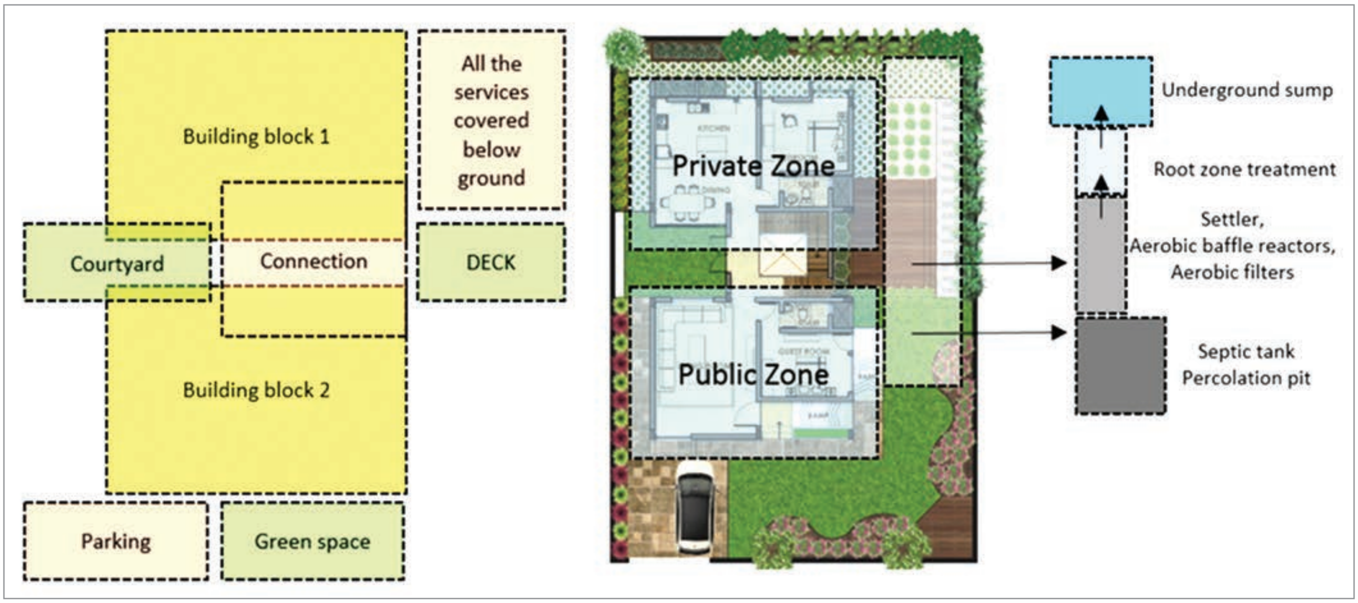

Figure 3: Conceptual zoning of spaces

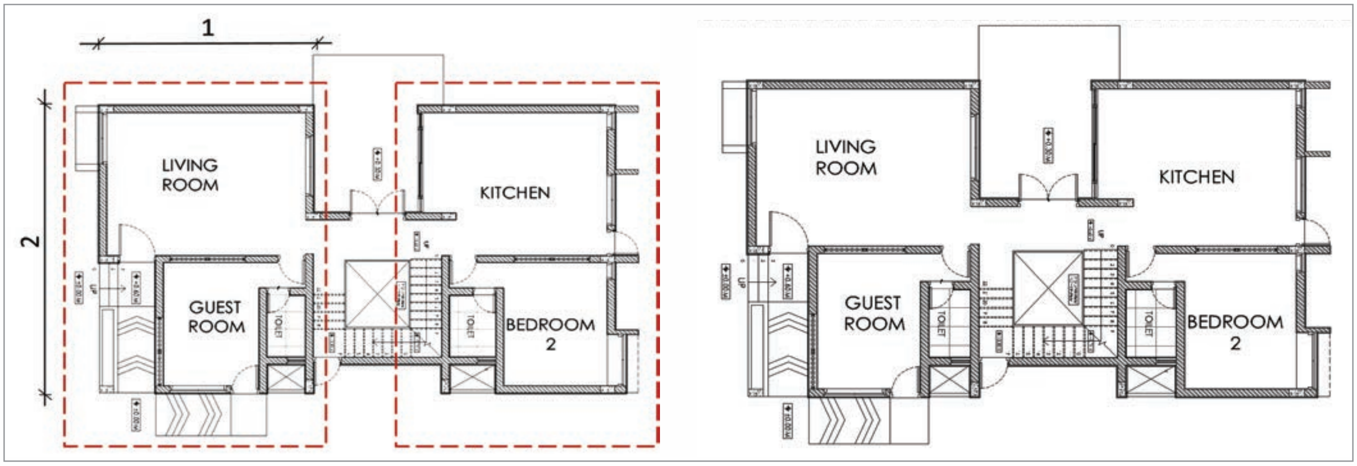

Figure 4: Ground floor plan (right) and first floor plan (left)

This resulted in an iterative process that required the designers to go back and revisit certain decisions as more information became available. For example, the building plan and its location on-site was revised twice based on the analysis for energy performance and requirements for on-site water treatment. By staying true to the performance goals, the team was able to agree upon the design revisions needed and the direction to be taken. All energy analysis was done in Design Builder which has an Energy Plus simulation engine.

Pre-design Analysis

The pre-design energy analysis showed that the most suitable geometry for the home was a plan aspect ratio of 1:2 and 15% window to floor area ratio, elongated along the east-west axis. Of all the options considered, this geometry maximized the comfort at 5,597 out of 8,760 hours in a year. All shading devices on windows were designed using shading masks to block direct solar radiation from morning (07:00 am) to evening (5:00 pm).

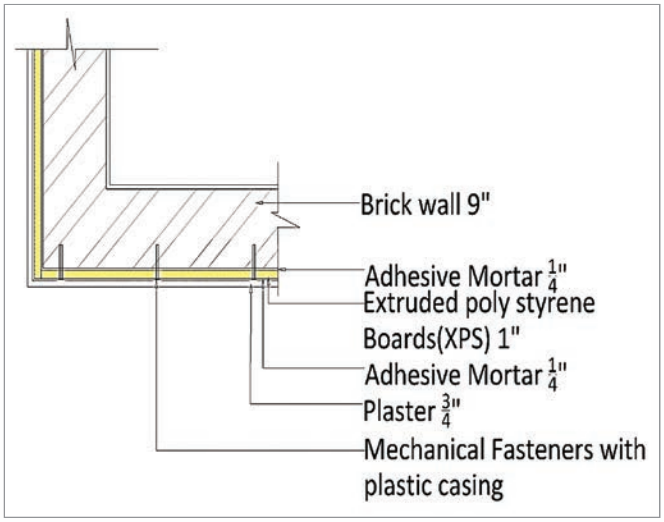

Figure 5: Wall plan – XPS fixing detail

Envelope Optimization

High-performance envelope assemblies were designed for high insulation, low thermal bridging, ease of construction, durability, termite and insect resistantance along with moisture and mold resistance. Since Oasis Abode is to be operated in mixed mode, air tightness is designed for when the building is mechnically cooled. The wall assembly has 230mm thick brick thermal mass with additional layers that include plaster on interior, and 25mm XPS for insulation and plaster on the exterior. This thermal mass cools the spaces by absorbing the interior heat during the day and cooling and recharging the thermal mass during night time, when the windows are open to the cool breeze through the home. Window openings and wing walls were designed to provide each room with cross ventilation for the prevailing wind direction.

HVAC System and IAQ Optimization

To design the HVAC system, load calculations were done using Residential Load Factor method found in ASHRAE Fundamentals 2013. The parameters considered for the heat load calculation are the thermal property of the opaque envelope (U-value), number of openings, fenestration thermal properties (window U-value and SHGC), interior loads (lighting, equipment and number of occupants), exfiltration and infiltration loads. The system used in Oasis Abode is variable refrigerant flow (VRF) by Daikin. A VRF system is chosen due to its higher Coefficient of Performance (COP) – 5.04 compared to 3.4 for a conventional split system. Indoor units of 1.14 TR (4 kW) are used for the guest bedroom and bedroom 2, and 0.9 TR (3.2 kW) for bedrooms 3 and 4 *(Figure 6)*. Although the lifecycle cost of a split unit was lower due to its significantly lower first cost, the team chose the VRF system because it helped them achieve a net zero energy performance. An Energy Recovery Ventilator (ERV) unit supplies fresh air when the building is in air-conditioned mode. The conditioned spaces are stacked over each other to reduce the duct length for reduced capital cost and easy installation. Further, friction losses were reduced by reducing the duct turns as shown in *Figure 6*.

To maintain the indoor air quality for the occupants, a three-step approach was followed. The first step was to analyze the data of ambient air of Jaipur for pollutants such as PM2.5 and PM10, sulphur dioxide and nitrogen dioxide. The second step was to reduce the indoor concentration of pollutants and maintain ventilation rates as per ASHRAE 62.2: 2010. The last step was to design the ventilation systems and the construction assemblies to filter outdoor pollutants and reduce the impact of moisture and mold formation.

Low volatile organic compound (VOC) materials in paints and furnishings were used to reduce indoor air pollutants. The ventilation rates for the residence were calculated from *ASHRAE Standard 62.2 (2010): Ventilation for Acceptable Indoor Air Quality in Low Rise Residential Buildings* for each space in the house. They helped to determine flow rates for the supply and exhaust fans. A MERV 16 filter in the ERV reduces the concentration of particulate matter in the outdoor air supplied in the AC mode. A Philips AC 2882 air purifier with a clean air discharge rate (CADR) of 150 m^3/hr cleans the room air in the naturally ventilated spaces.

Lighting and Day-lighting

Although lighting does not contribute to a large portion of energy consumption in residences, Team Kill Bill optimized the lighting to minimize its energy impact. Windows were designed with day-lighting analysis done in Velux software to eliminate any lighting use in the daytime. For the Oasis Abode, the goal was to use light sources with maximum luminous efficacy (lumens per Watt) and provide optimum illuminance levels for each space for a well-lit home. The lighting design requirements for residential spaces are based on recommendations by the Illuminating Engineering Society of North America (IESNA). Using high reflectance surfaces, the number of lamps required is calculated for each room

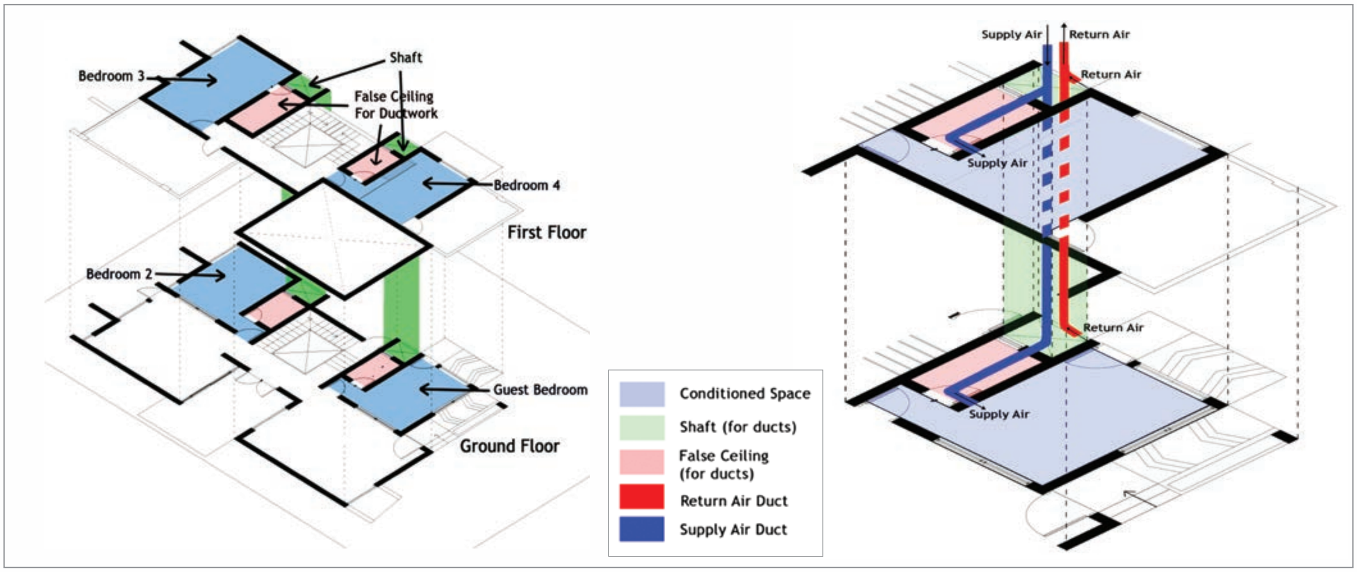

Figure 6: Isometric view of the ducting of HVAC system

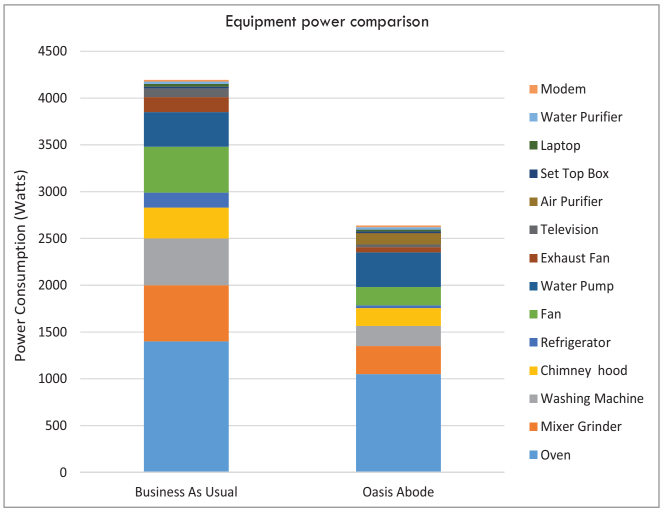

Figure 7: Reduction in equipment power for Oasis Abode

with the Lumen Method. The overall design strategy is a task-ambient system where the ambient system provides 85 lux and the task system provides an additional 50 lux. The light sources are selected based on Bureau of Energy Efficiency's (BEE) Star Rating program. The lighting system thus designed results in 72% reduction in lighting energy when compared to the business-as-usual scenario. The payback period for lighting is just over one year.

Energy Efficient Appliances

The equipment power density of a typical four bedroom Indian home is 20 W/m² and that of Oasis Abode is 12.5 W/m². This reduction of 40% was achieved by selecting BEE five star rated efficient equipment, viz. refrigerator, oven, television, washing machine, chimney hood, exhaust fans and ceiling fans.

Renewable Energy Integration

Solar photovoltaic (PV) is necessary to produce energy on-site and achieve a net zero energy home. Life cycle cost analysis of two options – fixed PV and PV with a tracking system, showed that the fixed frame PV system has a lower life cycle cost for operation of over 25 years. The total area occupied by PV is 25 m², which fits on the south facing sloping roof and generates 5,974 kWh/year.

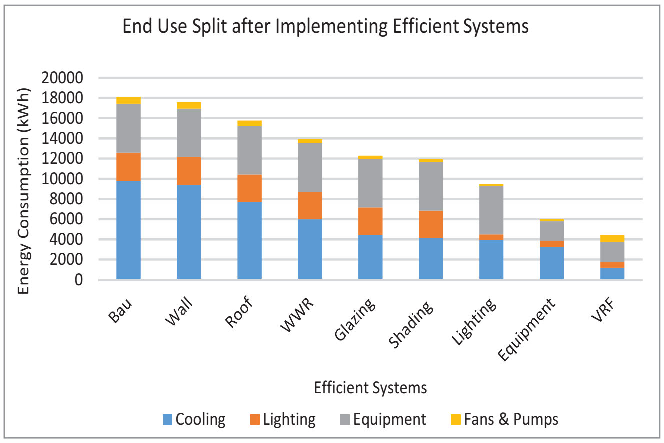

Figure 8: End use spilt after implementing efficiency measures

Energy Performance

Energy conservation measures (ECM) for building envelope, shading design, window sizing, glass properties, lighting, equipment and HVAC system are incorporated in the design to improve energy efficiency. While the HVAC system reduced the energy consumption most significantly, the other measures also helped to reduce the cooling load. See *Figure 8*.

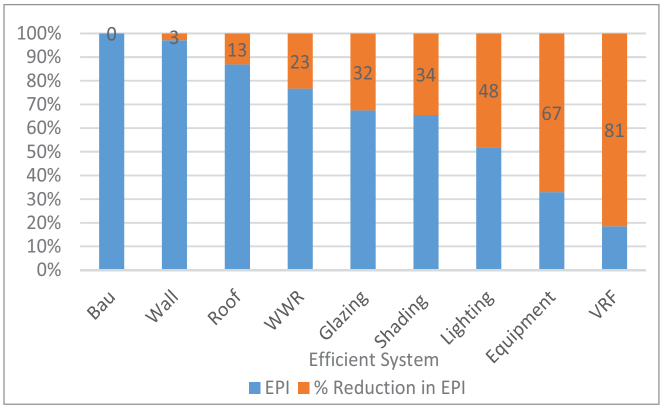

Figure 9: Successive reductions in energy consumption

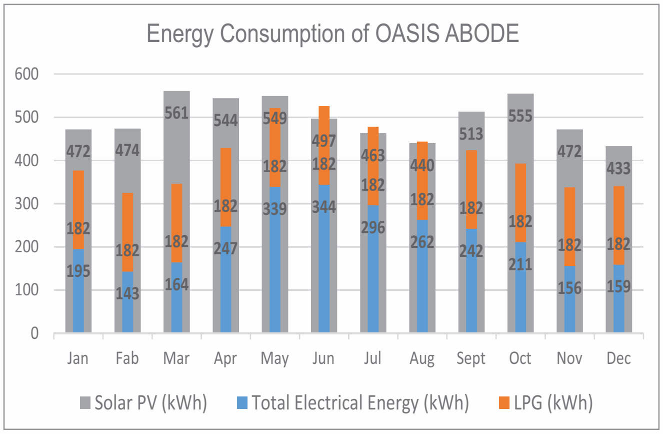

Figure 10: Net zero energy balance

Figure 9 shows the successive reduction due to each ECM on the EPI of building. Making building envelope tighter, they were able to reduce the energy consumption by 34%. Use of BEE 5-star rated equipment and lighting made another major reduction of 23% in energy consumption. Finally, by using low energy cooling technique, they were able to reduce the energy consumption by 81% as compared to a Business-as-Usual (BAU) building.

The Oasis Abode has an annual electric consumption of 2,758 kWh and an additional 2,128 kWh consumed by LPG gas for cooking. The total consumption of 4,886 kWh is less than the 5,973 kWh generated by the on-site 8 kW PV system. Thus the team achieved a net positive energy performance. *Figure 10* shows the monthly energy consumption and generation. Except for the monsoon months of June, July and August, the PV system generates more energy than the total in consumption each month.

Zero Water Discharge

The design achieves zero water discharge by integrating rainwater harvesting with a grey water recycling system using a series of tanks, filters, and treatment systems. Roof top drainage and hardscape was designed to facilitate rainwater harvesting.

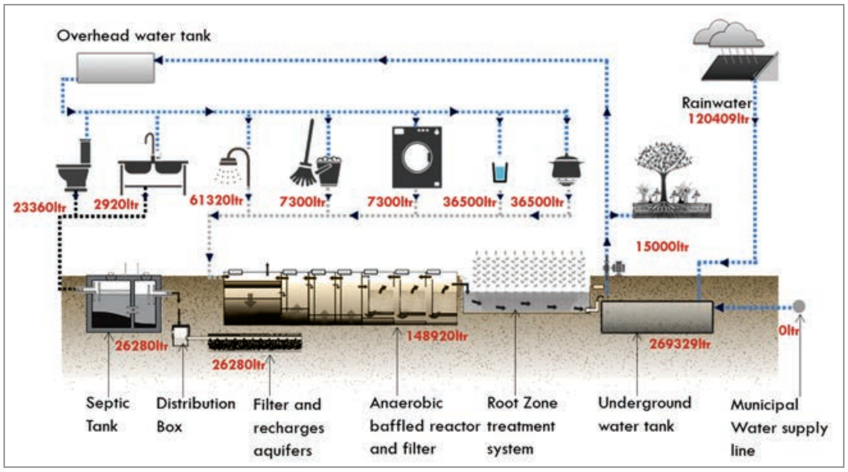

Figure 11: Annual water cycle showing zero discharge and zero municipal supply

Figure 11 shows the water cycle and the water quantity flows, and that no water is required from the municipal water supply line. By harvesting all the rainwater from the hardscape and roof areas into an underground tank, the design achieves a zero storm water discharge. Grey water from showers, clothes washing, floor cleaning and food washing is treated by the anaerobic baffled reactor and the root zone system, and is added to the rainwater tank for reuse in irrigation and flushing. Additional treatment with a Reverse Osmosis system makes the water available for drinking. Black water from toilet flushing and dishwasher is separately discharged into the septic tank, which then flows in to the distribution box and filters and recharges the groundwater aquifers. The entire water cycle including the rainwater and grey water was balanced with detailed calculations to meet the demand of the occupants throughout the year. This results in zero discharge to the municipal sewers and zero demand from the municipal water supply line.

Financial Performance

The team's discussion with the bankers showed that they prefer a debt to income ratio below 40%. The improvements in the building systems for net zero energy water and improved air quality for Oasis Abode resulted in 35% higher construction cost than the typical house. The construction cost is Rs.44,10,000 and the value of land purchased is Rs.75,00,000. So, after adding up other expenses of financing, overhead and general costs, marketing costs, and sales commission, the total cost of this home is Rs.1,61,72,000. To make Oasis Abode an affordable home, the team implemented several strategies to reduce the debt and increase the income of the residents. The guest bedroom with its separate entrance serves as an Airbnb rental to supplement the income. The higher indoor air quality home reduces the family's healthcare costs. City sewer and storm water connection fees are eliminated. Rebates for PV systems reduce their costs. With a net-zero energy and water home, all energy and water utility bills are also eliminated. Together, these strategies help achieve a debt to income ratio of 39%.

Conclusions

The team was able to achieve a net-zero energy design that consumes 20 kWh/m^2/year and generates more than that with an 8 kW rooftop solar PV system. The design is energy efficient as a result of measures included in every building system, including the selection of efficient appliances. Water consumption was reduced by 25% by using low flow fixtures, and the recycling strategies make this a net-zero water home. Even though the construction cost of this home is 35% higher than a typical house, team Kill Bill used innovative strategies to achieve a debt to income ratio of 39%. Designed using *Vaastu* principles, and with an aesthetic design that would make the house fit in the Jaipur neighbourhood, Oasis Abode is intended to be an easily marketable solution for developers.

The Race to Zero competition provided the M. Tech. BEP students an opportunity to apply what they learn in their curriculum towards a practical solution that was evaluated by building science, construction and real estate experts in the jury. The students have shown that sensible design using an integrated team approach supported by robust analysis can produce affordable high performance designs that are a need in India.

For further details, contact: Prasad Vaidya, Professor and Area Chair: Building Energy Performance, CEPT University, Ahmedabad.

Acknowledgements

1. Team Kill Bill worked under the guidance of faculty members of the M. Tech. BEP program. Professors Prasad Vaidya, Agam Shah, Rashmin Damle, Michael Apte and Rajan Rawal guided and supported the team throughout the competition.
2. Mitsubishi Electric India helped with identifying equipment for HVAC systems and their costs. This helped the team analyse system alternatives to maximize energy savings.
3. Guardian Industries provided specifications of the glazing alternatives available in the market, which were used as inputs for energy simulations.
4. Volpak Systems Pvt. Ltd. provided overall HVAC design review including assistance with duct and piping layout.
5. Kamal Cogent Energy connected the team with local vendors for costs of other building materials.
6. Four team members travelled to the USA with funding support from the Centre for Advanced Research in Building Science and Energy (CARBSE) of CEPT University, and Mr. SMH Adil and others who donated online at a crowdfunding site.