A PROTOTYPE OF NET–ZERO ENERGY SCHOOL FOR HOT AND DRY CLIMATE IN INDIAN CONTEXT

Abstract

India is the seventh largest country in the world in terms of area. Being the largest democracy with more than a billion people, 29% of its population falls in the age group of 0–14. The elementary education sector of India is anticipated to be about USD 144 billion by 2020. This paper presents a solution for developing a Net-Zero Energy (NZE) school prototype with the concept of Environment and Building-as-a-Learning Aid (E-BaLA). The design is an integration of the built environment with playscapes, urban farming, water conservation, biodiversity park, E-BaLA elements, and photovoltaic systems. It meets the Living Building Challenge (LBC) standards and the Advanced Energy Design guide for K–12 school buildings with an EUI of 44 kWh/m²/year. It is net positive by 11% and achieves high air quality as well as comfort standards with 189 unmet hours. Classroom spaces use evaporative cooling while most other spaces use VRF systems. The proposed electric lighting has achieved 300 lux with an LPD of 4.5W/m². Low flow fixtures and root zone treatment are used as water efficiency strategies. Compressed Stabilized Earth Blocks (CSEB) manufactured on site reduce the embodied energy. When compared to a conventional school building, the capital cost is 6.8% higher, and the operating cost is 28% lower with an ROIC of 12.9%.

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Keywords

Net-zero school, embodied energy, reduced carbon footprint, low operating cost

Introduction and Background

With India's developing economy, there is a substantial portion of society that needs access to education. The education system is yet to achieve excellence compared to many other countries. Better quality of education in terms of teaching, curriculum and extra-curricular activities require funding.

In response to trends such as climate change, demographic shifts, increasing communal intolerance, and rapid technological advancements, most countries have accepted the fact that education has a key role to play in building healthier, happier, and peaceful societies.

A summary of a proposed Central Government School of India—Kendriya Vidylaya—is provided in this paper. It is one of the largest school chains in the world with 1,137 schools in India and three operating outside India. The aim of the proposed school 'Learn Unplugged,' is to provide quality education at an affordable cost with E-BaLA incorporated in the school curriculum and project design.

Learn Unplugged is a net-zero energy campus in Jodhpur, in the Indian state of Rajasthan with a population of over 1 million. It is anticipated that the city's economy will double by 2031. The migration rates into the city are at 14%, and the population will increase by 32% in the next 15 years (Figure 1). This will shift 30% of the population to middle-income groups and 8% to high-income groups.

While Jodhpur falls in the hot-dry Climate Zone 2B according to IECC (Table 1), it experiences 30% higher cooling degree days than Phoenix, Arizona. (This comparison is made for a general understanding for a global audience.)

Better quality of education in terms of teaching, curriculum, and extra-curricular activities require funding. Government grants are inadequate to support these activities and to meet the operational budget of the school.

Parameters	Jodhpur, Rajasthan, India	Phoenix, Arizona, USA
Average maximum temperatures °C	43	45
Average minimum temperatures °C	0.5	2
Annual RH levels (%)	48.3%	34%
Solar radiation-Annual average (W/m²)	525	463
Average Wind speed (m/s)	2.08	2.9
Cooling Degree Days (CDD)	3110	2391

Table 1: Climate parameters of Jodhpur and Phoenix.

This deteriorates the infrastructure of buildings and affects the health of children (Figure 2). Learn Unplugged has addressed these issues for better student health and productivity.

The design is expected to meet the criteria of the Living Building Challenge, Advanced Energy Design Guide for K–12 School Buildings, Energy Conservation Building Code of India (ECBC, 2017), National Building Code of India (NBC, 2016), ASHRAE 62.1 Indoor Air Quality standard (2013), and Bureau of Energy Efficiency (BEE) star ratings.

The design goals were to:

— Achieve net positive performance for regenerative design, where 100% of the project's water requirements are met by rainwater and recycled water on-site and recharge groundwater.
— Incorporate E-BaLA where building and landscape elements are used for an interactive learning experience.
— Incorporate strategic landscape for nutrition and heat mitigation, where 30% of the site is reserved for biodiversity and 5% for edible gardens.
— Use restorative construction and achieve net positive waste, where 75% of the building materials are green certified and locally sourced.
— Reduce the operational cost to achieve an ROI comparable to 10-year fixed deposit schemes in India, currently at 6.25%.
— Provide occupant health and comfort, wherein thermal comfort as per Indian Model for Adaptive Comfort (IMAC) standards for operative temperatures are met varying between 20°C and 30°C. This also requires meeting the WHO Air Quality Guidelines (AQG) for PM 10 of 50μg/m3 and PM2.5 of 25μg/m3.
— Support climate change action, where Green House Gas (GHG) emissions are to be reduced by 50% when compared to a Business-As-Usual (BAU) scenario.

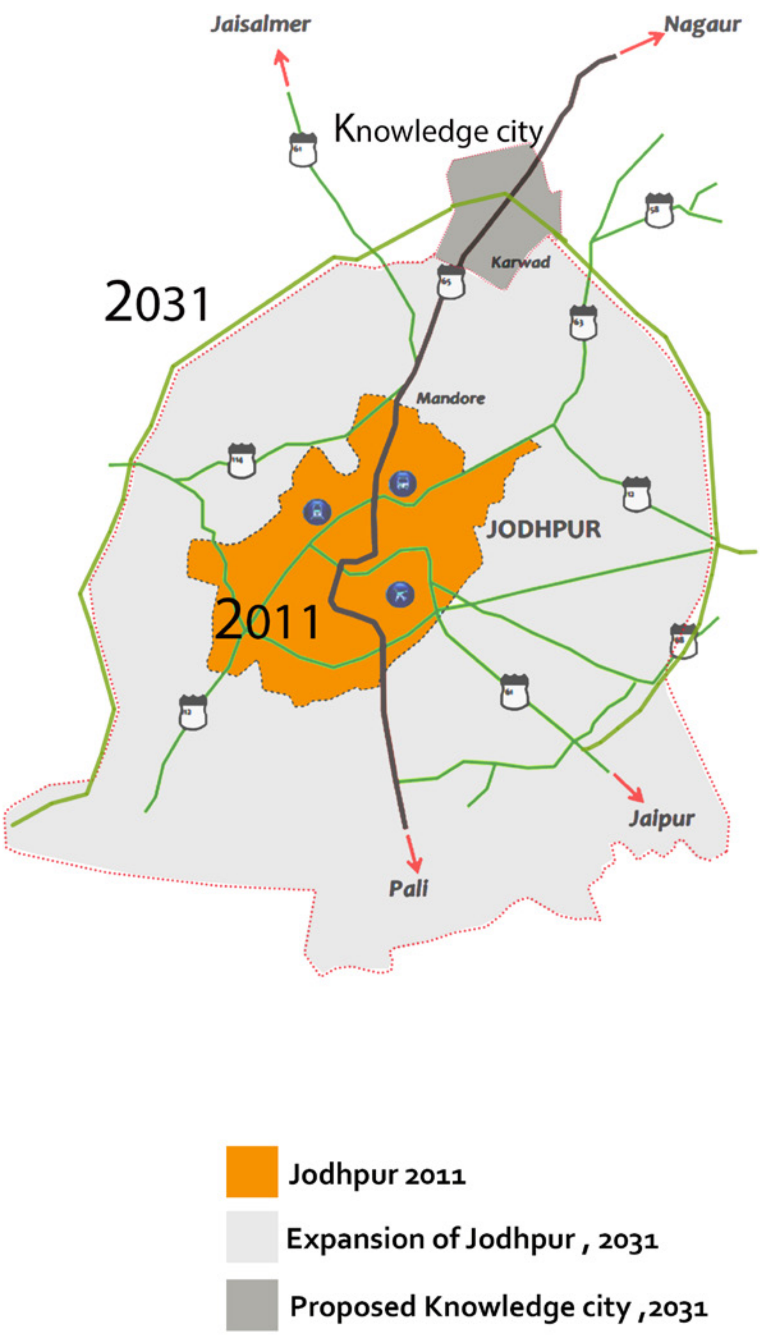

Figure 1: Population growth pattern of Jodhpur.

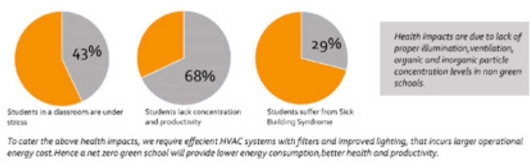

Figure 2: Health impacts of a non-green school. (Source: Singh & Arora, 2014.)

Methodology

The design team consisted of members with design expertise and field experience in architecture, mechanical engineering, civil engineering, planning, and landscape. The principles and process of integrated design were followed as per Keeler and Vaidya (2016). During the design process, preliminary decisions were taken based on research and analysis, which included pre-design simulation for energy, water, and daylight. Iterations were explored using various combinations of massing, form, building envelope systems, passive design strategies, and HVAC systems.

Design Charrettes were organized to exchange and develop new ideas amongst various teams working in different domains. This was done to address and resolve various issues and to make informed decisions. The performance of the design strategies was quantified through simulations. Within the Design Charrette structure, allowing each team member to contribute ideas and identify concerns related to each design issue maximized creativity and innovation. This approach enabled the team to ensure that design issues were explored holistically. Groups were formed to focus on specific goals related to energy, carbon emissions, zero water discharge, finance, and waste management.

ENERGY ANALYSIS

Initially, to understand the passive strategies that can be implemented in the design, the climatic conditions were studied using Climate Consultant. This helped in developing permutations and combinations with the help of various parameters like orientation, window-to-wall ratio (WWR), and aspect ratio.

Five-zoned model simulations were carried out in DesignBuilder and the number of comfort hours was used as the governing performance parameter which led to the selection of appropriate building geometry.

According to the simulation results in Table 2, the longer sides facing north and south with 15% WWR and aspect ratio of 1:3 was determined to be the most optimum geometry for this site. The maximum comfortable hours of 6,248 was achieved.

Orientation	Aspect ratio	Comfortable Hours
0° Longer sides facing north and south	1:1	6152
	1:2	6242
	1:3	6248
	2:3	6211
90° Longer sides facing east and west	1:1	6152
	1:2	6001
	1:3	5964
	2:3	6068
45° Longer sides facing northeast and southwest	1:1	6085
	1:2	6047
	1:3	5921
	2:3	6057
135° Longer sides facing northwest and southeast	1:1	6085
	1:2	6061
	1:3	6022
	2:3	6082

Table 2: Pre-design parametric analysis.

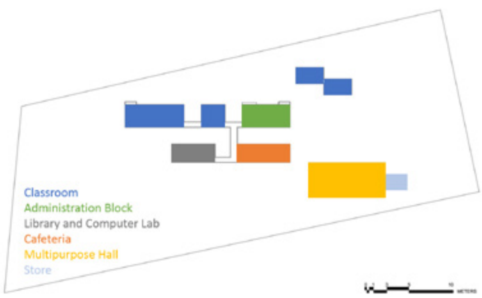

Figure 3: Zoning as per shoebox analysis.

The architectural design team used this analysis to further develop the building footprint. The same configuration was followed in all the zones and were linked as per the required connectivity, as seen in Figure 3.

The BAU building was simulated at various stages and its Energy Conservation Measures (ECMs) were obtained. To derive at all the ECMs, the following analysis was done:

WALL AND ROOF ASSEMBLY

For construction assembly, various materials were listed based on ECBC (Bureau of Energy Efficiency, 2017) compliances. Simulations were run in DesignBuilder to identify the highest performing, air-tight, free-from-condensation and thermally insulated assembly. The envelope (Figures 4 and 5) was designed to be durable, low cost and feasible to construct using locally available construction technology. Special attention was taken to avoid thermal bridging. Condensation analyses using a glazer diagram were also carried out.

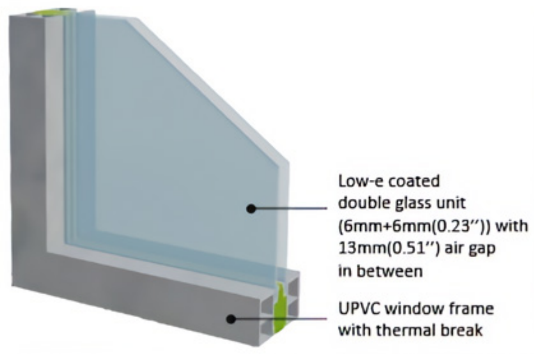

Figure 4: Typical glazing assembly.

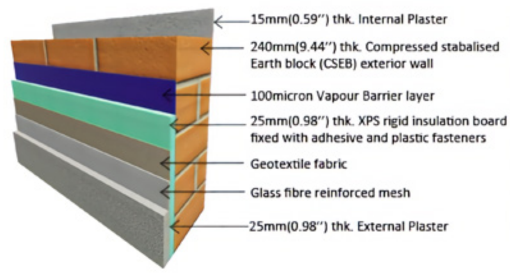

Figure 5: Typical external wall assembly.

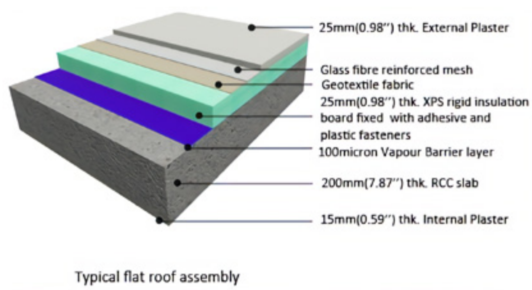

Figure 6: Typical flat roof assembly.

GLAZING

ECBC compliant glazing materials were considered for the assembly. Various glazing options were explored to maximize daylight in the building by optimizing the Visual Light Transmittance (VLT). Highly efficient window glazing (Figure 6) with low U-value, SHGC and high VLT values complying with ECBC has been proposed.

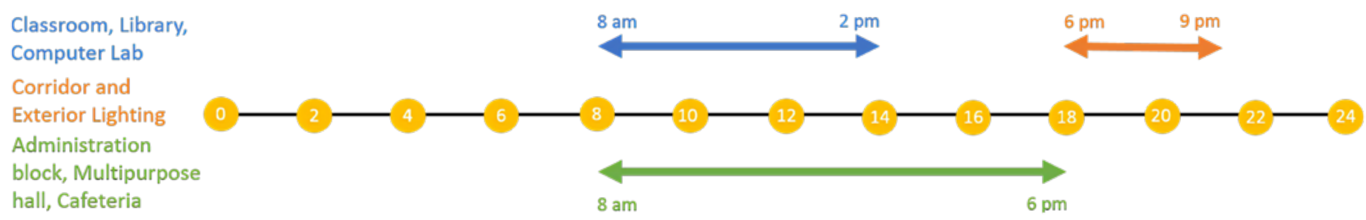

Figure 7: Timeline showing occupancy, lighting, equipment, and HVAC schedule for operating hours.

WINDOW-TO-WALL RATIO (WWR)

The window area distribution on the envelope was considered and optimized through iterations. After a five-zone simulation result, longer sides facing north-south orientation and WWR of 15% was found to be optimum. This orientation also minimized cooling loads by protecting the classrooms from the harsh south, east, and west sun exposure. After daylighting analysis, WWR on north facade was increased to take advantage of the available daylight and provide excellent views to the outside. A deep roof overhang was used to shade the facade from the south sun.

LIGHTING POWER DENSITY (LPD)

For lighting standards, the NBC (Bureau of Indian Standards, 2016) and ECBC (Bureau of Energy Efficiency, 2017) were referred, which suggested ideal illuminance levels and minimum LPD requirements in the classroom. Further, energy efficient fixtures with much longer life, improved light quality as compared to fluorescent fixtures and lesser LPD were selected. Further, the number of fixtures were optimized through simulations in DIALux.

EQUIPMENT POWER DENSITY (EPD)

Due to the unavailability of Energy Star program in India, an alternative program introduced by the government of India, the Bureau of Energy Efficiency (BEE) star label program was followed for the selection of appliances. The BAU case of the equipment required for the project was listed and their EPD was calculated. Further, it was reduced by using BEE star rated and new technology equipment. The cost of appliances and their power consumption was compared to the BAU scenario.

HVAC: EVAPORATIVE AND VRF SYSTEM

Iterative energy and financial analyses were done to choose the appropriate system. Cooling loads and ventilation standards were referred from ASHRAE fundamentals (ASHRAE, 2013) and ASHRAE 62.1 (ANSI/ASHRAE, 2013) respectively. The process was initiated with the comfort analysis as per Indian Model for Adaptive thermal Comfort (IMAC) adopted in the NBC 2016 of India. Additionally, daylighting sensors and controllers were considered through which sufficient illuminance levels were maintained throughout the year. Occupancy sensors were also employed to detect the presence or absence of people and turn lights on and off accordingly. The sensors were programmed as per the school schedule. The schedules for occupancy, lighting, equipment and HVAC systems were referred from the ECBC.

Carbon Emissions Analysis

Carbon footprint is the measure of direct and indirect GHG emissions associated with all the activities during the life cycle of the product. Assessment of carbon emissions and embodied energy of Learn Unplugged was done.

A bill of quantitates was created for all the materials used in the project. The emission equivalence values coined by International Finance Corporation (Union & IFC, 2017) for the Indian context, the carbon emission contribution of the entire facility was calculated. Transportation emissions for each material were calculated using Kumar, Buddhi, & Chauhan (2012). Local suppliers for various materials, closer to the site were identified to reduce carbon emissions due to transportation. The BAU construction refers to a two-storied structure, and the embodied energy and CO_2 emissions for the same were retrieved from Kumar et al. (2012). Through the assessment of base case emission contribution, various strategies like use of low embodied energy, recyclable materials, IGBC certified materials (CIIGBC, 2012) and low energy cooling systems were employed to reduce the carbon footprint.

Zero Water Discharge Design

Jodhpur has an annual rainfall of approximately 431mm (M K & Kaur, 2017) and the maximum amount of rainwater is available in the months of July and August. To calculate the amount of rainwater that can be stored, assessment of run-off coefficients for different surfaces were carried out. Water from the rooftop, pedestrian, parking space and driveways were considered. The annual water consumption through the fixtures was calculated based on the baseline flow rate for plumbing fixtures as per the IGBC Green School rating (CII, 2015). Low flow and economically viable plumbing fixtures available in the market were selected based on the Uniform Plumbing Code (UPC) of India to further reduce water consumption. The per day per capita drinking water requirement of children and adults was calculated based on Howard & Bartram (2003).

For landscape water calculations (US Department of Energy, 2010), turf and landscape type were identified with an irrigation area of 7665 m². Drought tolerant plants were selected and drip irrigation system type with regular maintenance and proper scheduling were considered. Further, annual landscape water use was determined.

Water demands for HVAC systems were calculated as part of for further analysis. Calculations for zero water discharged were developed considering all the strategies like rooftop rainwater harvesting, stormwater collection, low flow fixtures, drinking water, low water consuming plants and HVAC systems.

To meet the water demands on site, different treatment plants were studied and analyzed to recycle greywater as well as Blackwater.

Financial Analysis

Life Cycle Cost Analysis (LCCA) was used for evaluating the economic performance of the school for a lifetime of 20 years. Hence, the initial monetary investment with the long-term running expense of the school building was justified. The LCCA was based upon the assumption that the proposed building design option meets the targeted performance of a Net-Zero Building. The total cost of the proposed building was thus estimated which included initial construction cost, operation cost, maintenance and repairing cost, revenue and utility bills.

LCCA for two design configurations was carried out to understand the trade-offs between initial costs and operational costs for 20 years. This helped to identify and justify the cost of the design and determine the period of incremental payback. Various stakeholders like school owners, financial advisors, investors were interviewed to understand capital investment and the typical scenario of capital flow. Financial analysis was approached through the following steps:

ESTABLISHING FINANCIAL GOALS

To demonstrate market viability to the government, a goal of Return on Invested (ROI) capital of 6.25% was established which is comparable to the current 10-year fixed deposit schemes in India.

DEVELOPING TWO DESIGN ALTERNATIVES FOR LCCA

A BAU case against the proposed net-zero energy design case was developed and compared.

IDENTIFYING AND GATHERING COST INFORMATION FOR LCCA COMPONENTS

The following components were identified:

- **Capital cost:** The capital investment costs for land acquisition, construction, furniture, and the equipment which were required to operate a facility were included in the initial costs. Construction costs were calculated based on the documents issued by the local government (RUIDP, 2017). A detailed market survey was carried out for the items which were not available in the standards.
- **Utility cost:** Prevailing utility rates were used for the calculation (JDVVNL, 2017). Total energy consumption values for the base case and proposed case were taken from simulation results.
- **OM&R and replacement cost:** Cost per square foot based on international quality standards were considered for the calculation and hence leads to less depreciation (New Mexico Public School Facilities Authority, 2013).
- **Revenue:** Fee structure for the school and central government grants for the students specifically for Kendriya Vidyalaya were identified (Kendriya Vidyalaya Sangathan, 2013). Based on this, the total annual income of the school was calculated along with the residual value after 20 years.

For the LCCA calculation, an inflation rate of 6% and a discount rate of 5% was used.

CALCULATING THE RETURN ON INVESTED CAPITAL (ROIC) FOR 20 YEARS

Waste Management Plan

The 3R's strategy by Reducing, Reusing and Recycling of construction waste and the philosophy of 'Swachh Bharat (Clean India)' –a nationwide initiative by the Indian government (Swach Bharat Mission - Gramin, 2014) was proposed to be followed to tackle the waste generated. During construction, locally available materials which can

Month	No. of working days	Rainfall (mm)	Impervious Area of the rooftop (m²)	Water collected (l)	Stormwater collected(l)	Amount of greywater generated (l)	Amount of greywater recycled (l)	Total water available (l)	Total water demand (l)	Extra water left in the tank (l)	Amount of water in the underground tank (l)
June	20	40	2640	104282	265564	4800	3840	373686	193981	379327	573308
July	22	79	2640	207244	527767	6600	5280	740291	282880	836738	1119618
Aug	21	274	2640	723902	1843488	6900	5520	2572909	289781	3119866	3409648
Sept	0	13	2640	34321	87401	5400	4320	126042	223464	3022444	3245908
Oct	16	23	2640	59665	151943	5400	4320	215928	219208	3019164	3238372
Nov	22	0	2640	0	0	6600	5280	5280	448444	2575999	3024444
Dec	23	0	2640	0	0	4800	3840	3840	370745	2209094	2579839
Jan	18	0	2640	0	0	4200	3360	3360	351118	1861336	2212454
Feb	18	1	2640	2640	6723	6000	4800	14163	410001	1465499	1875499
Mar	22	2	2640	4488	11429	6600	5280	21197	448444	1038252	1486696
April	16	0	2640	0	0	6300	5040	5040	435942	607349	1043292
May	14	1	2640	1584	4034	0	0	5618	213725	199621	612967
	212	431		1138126	2898350	63600	50880	4087356	3887734	399242	24422044
			kgal/yr.	300	765	17	13	1079	1027	10.27%	

Table 3: Zero water discharge calculations.

be recycled were proposed. The 30cm excavated topsoil was preserved and used for landscaping. Empty paint cans left after the construction was to be used as planting pots. Crushed aggregates were to be diverted to make lean concrete mix. The broken tiles and glass waste were to be utilized for making mosaic tiles on walls & floors. Cardboard boxes & other packaging materials were to be diverted to the local recycling vendor. Hence zero waste was diverted to landfill/sites for incineration.

Swachh Bharat philosophy is required to be followed by the students for keeping the surroundings clean. For segregation of waste, color-coded dustbins were provided. Hazardous and E-waste like paints, glues, and printer cartridges were segregated for use of the red bin. Dry waste like a packaged water bottle, aluminum foils, and plastic bags was dumped into the blue bin. Toilet waste like tissue papers and sanitary pads were disposed into the black bin. Notebooks used examination sheets, subscription newspaper, and magazines, textbooks were planned to be sold to a recycler. Wet organic waste produced from the cafeteria and other organic wastes like leaves, shrubs, trees, twigs, silt, soil were to be collected in the green bin which was further recycled to make manure by composting.

Results

Through the integration of various active and passive strategies along with ECMs, HVAC system optimization, material selection and financial modeling, the building performance goals were met. The following results were obtained in the domain of building energy, carbon emissions, water management, finance and waste management of the project.

Energy

The EUI has been reduced from 124 kWh/m² to 44 kWh/m² (Figure 8) by implementing active and passive strategies in the design.

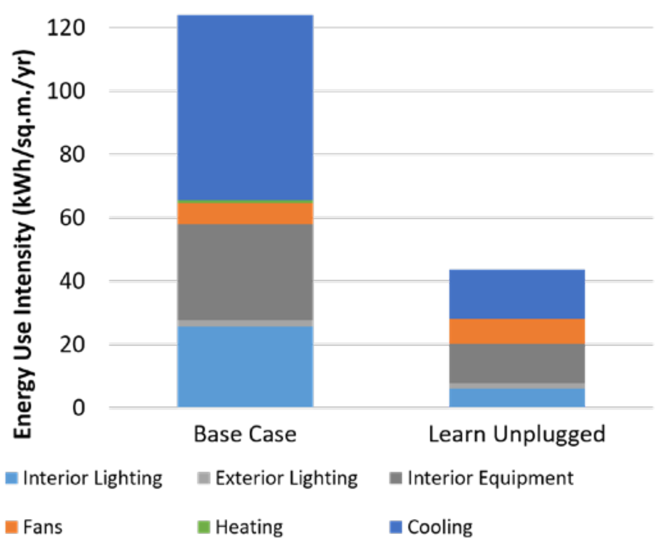

Figure 8: Base case and Learn Unplugged annual energy consumption comparison.

Passive strategies like orientation, aspect ratio, night flushing, and shaded corridors on the south have been incorporated. Heating is not required, and cooling and fan loads have been reduced by the energy conservation measures. Optimized WWR on each façade, reduced lighting, and equipment power density reduces the internal heat gains, thus decreasing the fan and cooling energy consumption.

The lighting energy consumption has been reduced by 57% using daylighting and occupancy sensor lighting controls. The Administration block, library, multipurpose hall and computer lab are cooled through VRF units (COP 4.2) and classrooms are cooled through Indirect Direct Evaporative Cooling (IDEC) units. Ventilation for the spaces served by the VRF systems has been provided by Dedicated Outdoor Air System (DOAS) units with Heat Recovery Wheel (HRW). In spaces where the IDEC units do not meet adequate comfort hours, VRF units have been used.

Following ECMs (Figure 9) has been used to reduce the energy:

NO HEATING ENERGY CONSUMPTION

The insulation which has been provided in the envelope and the window traps the heat inside the school building. Hence heating is not required during the winter months from November to February.

WALL AND ROOF ASSEMBLY

The wall assembly comprises CSEB and XPS insulation. CSEB is a low cost and low embodied energy material. XPS insulation has been provided to form an air sealed and airtight envelope. Cool roof with high Solar Reflective Index (SRI) paint and the green roof has been proposed to reduce overall heat gain through the envelope.

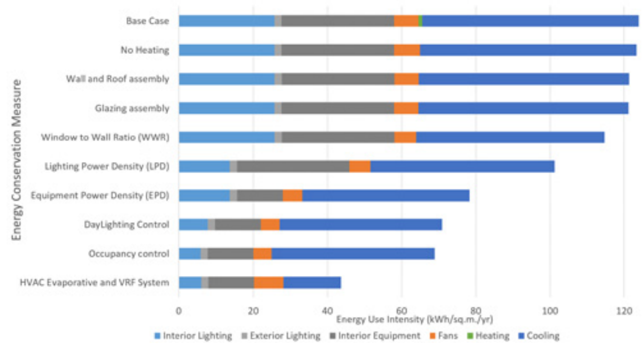

Figure 9: Energy use breakdown to energy conservation measure.

GLAZING

Low-e coated Double Glazed Unit with low SHGC and low U-value has been provided to reduce radiative and conductive heat gains through the glazing. The glazing has been selected to maximize the daylighting in the building by optimizing the Visual Light Transmittance (VLT).

WINDOW-TO-WALL RATIO (WWR)

The overall Window-to-Wall Ratio (WWR) has been reduced from 40% to 17%. An optimum WWR has been provided to reduce the cooling energy consumption and achieve Daylight Autonomy (DA) of 91% inside the building.

LIGHTING POWER DENSITY (LPD)

The objective of this ECM was to enhance visual comfort and reduce energy consumption. LPD has been reduced by 47% by providing low energy LED fixtures.

EQUIPMENT POWER DENSITY (EPD)

The EPD has been reduced by 60% by selecting BEE star rated equipment and new technologies that minimize the energy consumption without compromising on the comfort of the occupants.

DAYLIGHTING CONTROL

According to NBC 2016, the illuminance level required on the working plane, i.e., the classroom desks is 300 lux. Stepped lighting control has been provided which regulates the lighting as per the daylight received in the space to control the required illuminance level. This measure has reduced the lighting energy consumption by 43%.

OCCUPANCY SENSOR AND PROGRAMMABLE TIMING LIGHTING CONTROL

Lighting energy consumption was reduced by 23% by regulating electric lighting according to the occupancy of the space and programmed as per the schedules of the space.

HVAC: EVAPORATIVE AND VRF SYSTEM

The cooling energy consumption has been reduced significantly by 65% due to IDEC units and VRF system with DOAS and HRW.

Furthermore, energy is generated by the Photo Voltaic panels located on the rooftop of the multipurpose hall and parking lots. The annual energy consumption of the primary school is 146016 kWh/m^2/year and energy generation due to PV panels is 162671 kWh/m^2/year. Learn Unplugged is able to generate 11% of the excess energy that is more than the Living Building Challenge requirement of 5%, making it a net positive (Figure 10).

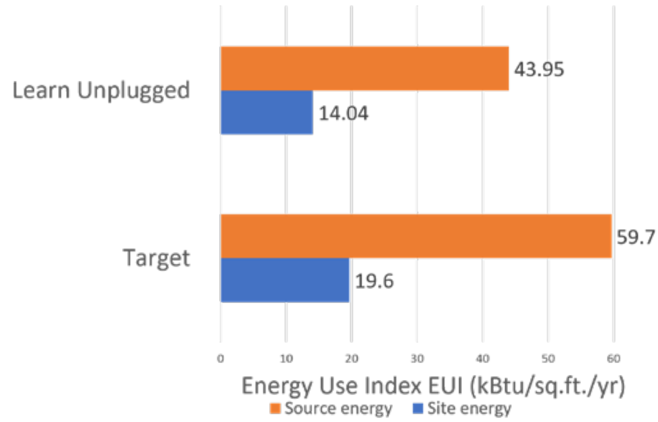

Figure 10: Base case and Learn Unplugged annual energy consumption comparison.

Carbon Emissions

Use of low embodied energy and recyclable materials such as CSEB, UPVC, recycled aluminum, and IGBC certified materials and finishes, low energy cooling systems were used to reduce the GHG emission contributions. In addition to this, a significant percentage of carbon sequestration was contributed by onsite generated PV energy, recycled water, and waste and urban farming. Emission equivalence of 1kWh energy produced by coal power plants is 120 times higher than the emission equivalence of energy produced by Photovoltaic cells. Learn Unplugged has 4 times lower carbon emissions and embodied energy compared to the BAU Indian construction (Figure 11).

ZERO WATER DISCHARGE

The runoff from the rooftop and storm water has been treated and stored in the potable water tank. Before entering the potable water tank, water passes through

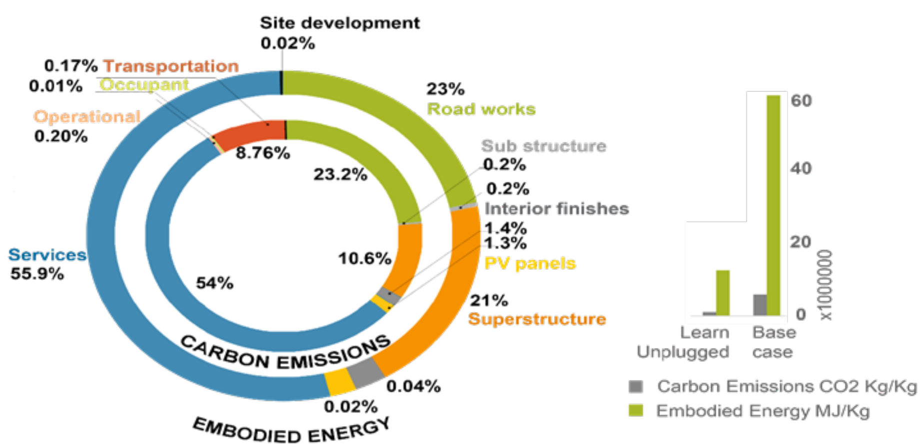

Figure 11: Carbon emissions and embodied energy emissions.

gravel, sand, mesh filters to remove silt, dust, leaves and other organic matter. This water has been used to fulfill the demands of drinking water and other potable water requirements. To provide safe drinking water, a 'Reverse Osmosis Filtration System' has been installed, which filters and reduces the Total Dissolved Solids (TDS) in water.

The surfaces of hardscape spaces have been designed with permeable concrete surfaces (Figure 12) for water to percolate through into the sub-grade. This stormwater collected in the subgrade is then channeled for treatment into the constructed wetland and discharged to the connected portable water tank through the pipes.By using low flow fixtures, a saving of 40% from the regular conventional plumbing system has been achieved.

A list of low water consuming plants has been chosen to conserve water and more efficient drip irrigation system has been used to deliver water at low pressure at the plant's roots.

Root Zone Treatment Plant has been developed to recycle water on site (Figure 13). It is a system which consists of anaerobic baffled reactor and filter, where grey water is purified and sent to the wetland created on site. The anaerobic baffled reactor is a sedimentation tank where the sludge sediments and treated water is discharged into the anaerobic filter. The anaerobic filter consists of cinder filter material which filters the water and is sent to the wetland. The water has been again treated in the wetland by water-resistant reed plants like canna lilies and provides oxygen to the passing water. The clean water which has been collected at the non-potable water tank is used to fulfill the demand for irrigation and flushing purposes.

The Blackwater from the water closet and the cafeteria kitchen sink has been discharged into the septic tank which is filtered and released to recharge the groundwater.

Based on the typical annual rainfall of 431mm, the project is achieving 10% extra water (Figure 14), and this serves as a safety factor. Hence the rainwater harvested and the recycled water satisfies the water demand of the occupants throughout the year.

Finance

The Kendriya Vidyalaya school has been funded through government grants for capital and operating costs. The analysis shows that the grants are inadequate to support the operations of a typical BAU school. This usually forces the school administration to defer maintenance and replacement of building elements into the future, resulting in sub-standard educational infrastructure.

Therefore, the school has been proposed with a financial model that avoids this issue.

As a result of the energy and water design, Learn Unplugged costs $2,166,573 which is 6.8% more than a BAU school building (Figure 15). However, there has been a significant reduction in energy and water bills for the proposed design. The facility has been enhanced as a community resource by renting the multipurpose hall during weekends and vacation months for events and functions.

Standard maintenance costs for such a facility includes $1.5/ft² annual operating costs and $5/ft² in replacement costs.

In the financial modeling, the base case building has been considered with 20% reduction in O&M and replacement budget compared to these values but Learn Unplugged can sustain 20% higher maintenance budget for the proposed design due to its reduced utility bills and additional revenue. The annual operational cost has been reduced by 20.84% compared to the base case (Figure 16) with an ROIC of 12.9% over a 20-year period with these strategies.

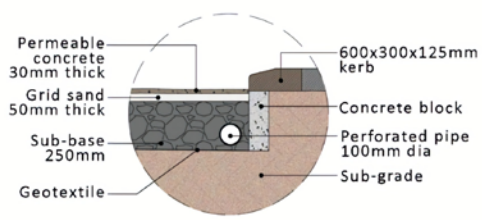

Figure 12: Stormwater collected from permeable concrete detail.

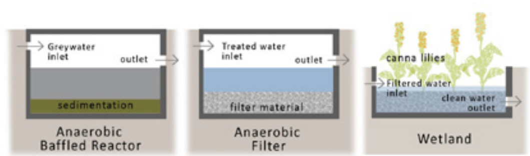

Figure 13: Schematic representing root zone treatment adopted at Learned Unplugged.

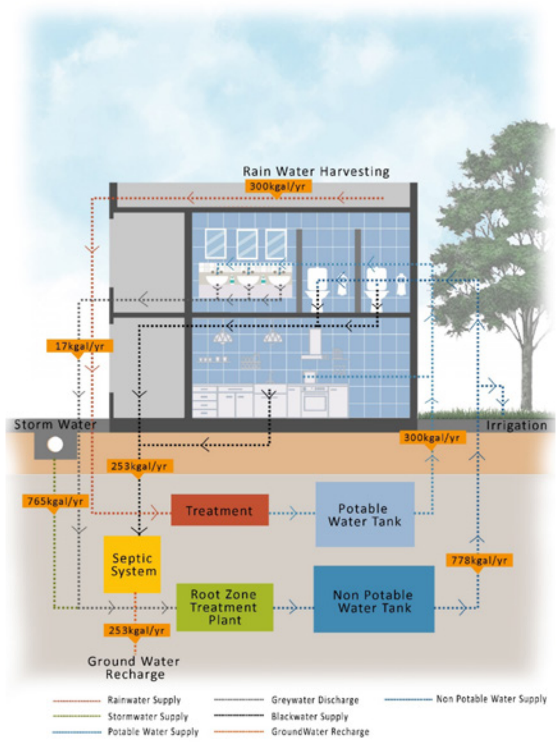

Figure 14: Zero water discharge.

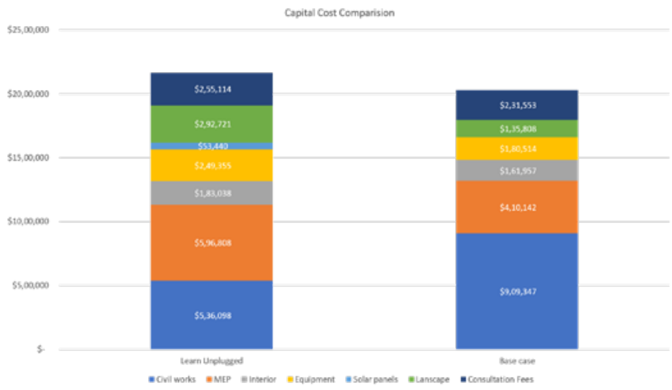

Figure 15: Capital cost comparison for base case and Learn Unplugged.

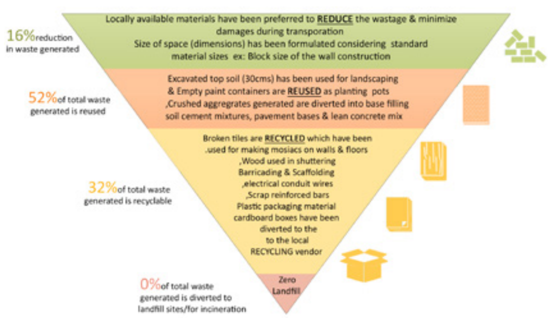

Figure 16: Life cycle cost comparison of base case and Learn Unplugged.

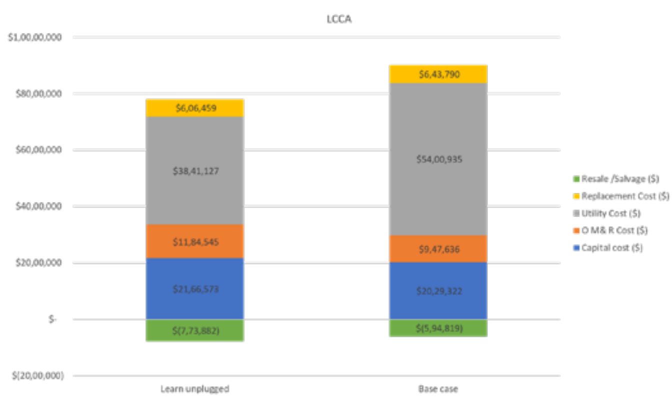

Figure 17: Schematic for construction waste management strategy for Learn Unplugged.

Waste Management Plan

By using the 3R's strategy, construction waste and the philosophy of 'Swach Bharat' – the following results were achieved (Figure 17).

— 16% of the produced waste was reduced.
— 52% of waste was reused within the project.
— 32% of the total waste generated was recycled.
— 0% waste was diverted to landfill/ sites for incineration

Conclusion

Considering the importance of the education sector in India, the goals have been achieved by designing a Net-Zero Building with an integration of built environment with playscapes, urban farming, water conservation, biodiversity park, Environment, and E-BaLA elements.

Learn Unplugged has achieved an EUI of 44 kWh/m²/ year. The net site energy of 26% lesser than the target EUI specified by the Advanced Energy Design guide for the K–12 building has been achieved. The total capital cost is 6.8% higher than the BAU case and the operational cost is 28% lower lesser with an ROI of 12.9% and payback of three years. The annual energy generation is 11% higher than the consumption of the school, which is also 6% higher than LBC requirements. This makes it a net positive school. Due to the use of locally available, low embodied energy materials and other strategies, the impacts of construction on climate change has been reduced. Hence 4 times lower carbon emissions compared to the BAU in Indian construction scenario has been achieved. Net positive water has also been achieved through zero water discharge.

To summarize, Learn Unplugged could be used as a prototype for hot and dry climate, where the total energy consumed in the form of electricity, water, and waste is generated with renewable resources. In addition to this, the carbon footprint has been minimized and an acceptable ROI is achieved.

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