

Ethos Science Fairs - Project Paper

Introduction:

As energy costs continue to climb and the urgency of climate change intensifies, transitioning to renewable and sustainable energy sources is no longer optional — it's essential. One of the most powerful places to start is in our schools. By powering educational institutions with renewable energy, we not only reduce long-term operating costs, but we also transform schools into living classrooms — places where students can witness sustainable technology in action every day. This hands-on exposure equips the next generation with the knowledge and inspiration to become climate-conscious leaders. If we want to build a more sustainable future, what better place to begin than with the changemakers of tomorrow?

This paper presents a forward-thinking design for a school powered entirely by renewable energy. The concept integrates multiple renewable energy technologies and sustainable systems, creating a model for how educational institutions can operate efficiently while minimizing environmental impact. More than just a blueprint, it offers a vision of how schools can lead the transition to a greener future — by combining innovation in energy with education for sustainability.

Design:

Building Layout & Orientation

- Shape:
 - Rectangular Shape: A compact rectangular form reduces surface area, which minimizes heat loss and gain. This makes heating/cooling more efficient.
 - 3 - Story Wing: 3 Stories Instead of 1 or 2: The smaller roof and footprint reduce heat loss, stormwater load, and land use. Shorter horizontal runs for plumbing and ductwork = lower pumping and fan energy
- Orientation:
 - North–South Orientation (Long Axis): The long side of the school faces North and South, which optimizes daylighting and allows South-facing windows to capture low winter sun for passive heating, while north-facing windows provide consistent, diffuse daylight with minimal heat gain. Having minimized east/west glazing, which would otherwise cause unwanted glare and solar heat gain in the mornings/evenings.
- Main Areas/Components:
 - Classrooms (floors 1–3)

- Cafeteria (1st floor, south end)
- Library/media center (2nd floor center)
- Gymnasium (North end of building, all 3 floors with double-height ceiling)
 - Lighting: High-lumen LED High-bay fixtures with motion sensors and daylight dimming controls
 - Efficacy: ~130–160 lumens per watt
 - Dimmable with motion and ambient light control
 - Long life (50,000+ hours)
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 - Power Supply: Directly from rooftop solar + battery storage for evening use
 - HVAC: Uses zones for HVAC for occupancy-based conditioning. Integrated with a central geothermal or air-source heat pump system (details below).
 - Located on the north end to avoid solar heat gain
 - An open structure allows natural ventilation options and passive cooling
- Elevator and stairwells on both ends
 - Elevator System:
 - High-efficiency regenerative braking model that feeds energy back into the system
- Rooftop: rotating solar panels, wind turbines
- Exterior: rain garden, rain barrels, solar-covered parking lot, white exterior (to reflect sunlight onto solar panels), and low-maintenance lawn

Renewable Features and Descriptions:

Window Placement & Daylighting:

- North and South Windows: These are generously sized and fitted with triple-pane, low-E glass to maximize daylight and minimize thermal transfer.
 - Reduces reliance on artificial lighting during the daytime
 - Improves student health, alertness, and productivity
- Light Shelves & Interior Glass: Bounce sunlight deeper into classrooms and hallways
 - Reduces lighting energy by up to 60%
 - Controlled with automatic dimmers and motion sensors

Rotating Solar Panels on the Roof:

- Technology: Dual-axis solar trackers with photovoltaic (PV) panels
- Function: Maximize solar energy capture by tracking the sun's movement across the sky
- Benefits:
 - Up to 30–40% more efficient than fixed solar panels
 - Best suited for flat roof spaces
- Key Components:
 - Solar panels (monocrystalline preferred for efficiency)
 - Tracking system (motors and sensors)
 - Inverters (DC to AC conversion)
 - Battery storage (optional for off-peak use)

Solar Canopies Over Parking Lots:

- Technology: Fixed-tilt PV solar arrays on steel canopy structures
- Function: Generate power while shading parked vehicles
- Benefits:
 - Dual-use of land (parking + energy)
 - Can be used to power EV chargers on site
 - Doubles as an energy source and a heat shield for parked vehicles
- Key Components:
 - Steel canopy structures
 - Solar panels (usually ground-mount grade)
 - Wiring and inverters
 - Optional EV charging stations

Wind Turbines on the Roof:

- Technology: Vertical-axis wind turbines (VAWTs)
- Function: Generate power from wind, especially in urban rooftop settings
- Benefits:
 - Works well with multidirectional wind
 - Lower noise and vibration compared to horizontal-axis turbines
 - Capture high-altitude wind, especially in open areas
- Key Considerations:
 - Local wind speed (ideally above 5 m/s consistently)
 - Roof load-bearing capacity
 - The local prevailing wind direction (face of turbines into prevailing wind)
- Output: Typically supplemental power (not base load), depending on turbine size (1–10 kW)

Micro-Hydroelectric from Gutters:

- Technology: Micro hydrokinetic turbines in downspouts or rainwater management systems.

- Gutters channel roof water into rain barrels and irrigation tanks
- Function: Generate small-scale power from rainwater flow
 - Used to flush toilets and irrigate landscaping, reducing the need for pumped water
- Benefits:
 - Innovative use of stormwater runoff
 - Educational opportunity for the water-energy nexus
- Challenges:
 - Seasonal and weather-dependent
 - Typically low yield; best for charging batteries or LED lighting
- Key Components:
 - Miniature turbines
 - Power regulators
 - Battery storage system for intermittent output

Biomass Generator from Cafeteria Waste:

- Technology: Anaerobic digester or small-scale biomass gasifier
- Function: Converts organic waste into biogas, which is burned to generate electricity or heat
- Input: Food waste, kitchen scraps, compostable materials
- Benefits:
 - Reduces landfill waste and methane emissions
- Output: Can produce both electricity and hot water
 - Biogas → electricity via generator (CHP)
 - Digestate → compost or soil amendment for school gardens
- Safety: Needs proper gas management and safety measures

Energy Storage & Management System:

- Technology: Lithium-ion battery storage + Smart grid integration
- Function:
 - Stores excess energy (e.g., from solar midday peaks)
 - Manages loads (e.g., HVAC, lighting, EV chargers) intelligently
 Software: EMS (Energy Management System) with real-time dashboards for educational use
- Benefits:
 - Smooths out energy use during low solar production or high demand

Energy-Efficient Lighting Fixtures:

- Throughout the School:
 - 100% LED lighting
 - 80–90% more efficient than traditional lighting

- Lifespan of 10–15 years reduces replacement energy and labor
- Daylight Sensors: Smart daylight harvesting sensors to dim lights based on available sunlight.
 - Reduce light output when natural daylight is sufficient.
- Occupancy Sensors:
 - Lights turn off when rooms are empty (in classrooms, gym, hallways, and restrooms)

HVAC & Thermal Comfort Systems:

- System Type:
 - Geothermal Heat Pump System (Ground Source):
 - Most efficient HVAC type (COP > 4.0)
 - Uses buried loops for consistent ground temperature year-round
 - Provides both heating and cooling from one source
 - May qualify for tax credits or grants
- Supplemental:
 - Solar Thermal Panels for pre-heating water or a radiant heat loop
 - Demand-controlled ventilation in the gym and cafeteria
 - Heat Recovery Ventilation (HRV) systems for fresh air with minimal energy loss
- Zoning:
 - Zonal HVAC control per floor and by function (classrooms vs. gym vs. kitchen)
 - Smart thermostats are tied to occupancy and outside temperature

HVAC System Zoning & Efficiency
- Geothermal Heat Pumps or High-Efficiency Air-Source Systems
 - Draws stable underground temperatures for heating/cooling
 - Reduces electricity use for climate control by up to 70%
- Zoned HVAC Design:
 - Each floor and room type (e.g., gym, classrooms, cafeteria) has independent control
 - Demand-controlled ventilation adjusts airflow based on occupancy
- Heat Recovery Ventilation (HRV):
 - Captures heat from exhaust air to warm incoming fresh air without using extra energy

Insulation Details (Energy Saving Envelope):

- Walls: Structural Insulated Panels (SIPs) with R-40+ rating
- Roof: Cool roof with foam insulation (R-60) - [using structural insulated panels or vacuum insulation]
 - Keeps heat inside during winter and outside during summer
- Windows: Triple-pane, low-E glass with thermal breaks; 40% of façade for daylight
 - Minimize unwanted heat gain/loss and noise

- Floor Slab: Insulated with rigid foam to prevent thermal bridging.
 - The foundation is sealed and insulated to reduce ground heat loss.
- Continuous Thermal Breaks: Prevent thermal bridging at windows, corners, and floor/wall joints

These features reduce HVAC loads by 40–60% compared to conventional buildings

Rainwater Harvesting & Landscape:

- Rain Barrels: Collect from roof runoff; used for toilets and irrigation
- Rain Garden: On-site stormwater management with native plants
 - Absorbs and filters stormwater, reducing energy used in municipal water treatment
- Native Landscaping: Low water demand, no pesticides needed
 - No grass lawns or fields (Substitute example: Clover)

Renewable System Integration by Zone

Zone	Energy Source	Special Considerations
Classrooms	Solar & Battery	Smart lights, ventilation, occupancy HVAC
Gymnasium	Solar & Wind & Storage	High-bay LEDs, zoning HVAC
Cafeteria	Biomass & Solar	Ovens, fridges, dishwasher on timed load
Library	Solar	Low-energy lighting, silent ventilation
Elevator	Battery Reserve & Solar	Energy-efficient regenerative system
Exterior	Solar Canopy & Hydroelectric	EV charging, irrigation

Summary of Structural & Layout Energy Efficiency Features

Design Feature	Energy Efficiency Benefit
North–South orientation	Optimizes solar gain/daylighting

Triple-glazed windows	Reduces heat loss/gain
High insulation + SIPs	Lowers HVAC demand
Zonal HVAC & HRV systems	Efficient temperature control
LED smart lighting + daylighting	50–80% reduction in lighting load
Multi-story layout	Reduces building envelope losses
Solar, wind, battery integration	On-site renewable generation
Rain capture & native plants	Reduces water pumping and irrigation energy

Example Energy Contributions

Source	Capacity (kW)	Contribution to Daily Load (%)
Rotating Roof Solar Panels	80	35%
Solar Panel Parking Lot Canopies	60	25%
Rooftop Wind Turbines	15	10%
Hydroelectric (Gutter)	2	1% (weather dependent)
Biomass (Cafeteria Waste)	20	15%
Battery Storage	100 kWh	Smooths out 14% peak loads

This distributed, hybrid system enables net-zero energy use and even off-grid capability in emergencies.

Cost & Function:

Capital Construction Cost Comparison

Category	Conventional School <i>(100,000 sq. ft.)</i>	Renewable-Powered School <i>(Same size)</i>

Base construction (standard finishes)	\$250–300/sq. ft. → \$25–30M	\$270–320/sq. ft. → \$27–32M
Energy-efficient insulation + materials	Standard (~R-20)	+\$3–5/sq. ft. → + \$300K–500K
Triple-glazed windows & daylighting	Standard double-glazed	+\$400K–600K
LED smart lighting system	Basic LED (non-networked)	+\$100K–200K
Geothermal or heat pump HVAC	Standard gas/electric HVAC	+\$800K–1.2M
Solar (roof trackers + parking canopy)	None	\$2.5M–3.5M
Wind turbines	None	\$200K–500K
Battery storage (100–200 kWh)	None	\$200K–400K
Anaerobic digester (cafeteria)	None	\$100K–150K
Rainwater capture & native landscaping	Traditional grass + sprinkler	+\$150K (low-maintenance plants, rain garden)
Rain barrels and plumbing reuse loop	None	\$80K–120K
Smart building management systems	Basic thermostat control	+\$250K–350K
Total Estimated Construction	\$25–30M	\$32–39M

- ☐ *Additional capital cost: ~\$6–9M more than a conventional school*
- ☐ *Up to 30% of this cost may be offset through federal IRA incentives, grants, and energy performance contracts (EPCs).*

Annual Operating & Maintenance Costs

Category	Conventional School	Renewable School
Electricity	\$150K–250K/year	\$0 (geothermal, solar, biomass)

Heating Fuel (gas, etc.)	\$50K–80K/year	\$0 (geothermal, solar, biomass)
HVAC maintenance	Medium-high	Lower (fewer mechanical parts, zoned)
Landscaping/water	~\$25K–30K (mowing, watering)	~\$5K–10K (native, rain-fed)
Lighting Replacement	Fluorescents every 3–5 yrs	LEDs last 10–15 yrs
Waste Disposal	High (food waste, landfill)	Lower (composting, digesting)
IT/Energy Monitoring	Basic meters	Smart BMS system, low cost after installation
Total Annual O&M	\$300K–400K/year	\$75K–150K/year

☐ *Annual savings:* \$150K–300K/year

20-Year Lifecycle Cost Comparison

Category	Conventional School	Renewable School
Upfront construction cost	\$28M (avg.)	\$36M (avg.)
20-year utilities + maintenance	~\$7M–8M	~\$2M–3M
Incentives and avoided penalties	\$0	~\$2M to -\$4M (incentives)
Total Lifecycle Cost (20 yrs)	~\$35M–36M	~\$34M–37M

☐ Break-even in ~12–15 years, with long-term cost advantage and resilience benefits (grid outages, climate control).

Cost Feasibility

- Upfront cost: Higher than a conventional school (by ~\$6–9M), but:
 - 30–50% of the renewable upgrades can be covered through federal tax credits (IRA), state incentives, and green building grants.

- Schools can enter Power Purchase Agreements (PPAs) for solar and battery systems, reducing or eliminating upfront cost while still achieving net-zero operations.
- Energy Savings Performance Contracts (ESPCs) enable school districts to build now and repay with future energy savings—without incurring an extra tax burden.

Many U.S. school districts (e.g., Boulder Valley, San Diego USD, Portland Public Schools) are already implementing versions of these systems at scale.

How the School Would Realistically Function at Full Scale

- Daily Operation:
 - Morning hours:
 - Solar energy ramps up, powering lighting, HVAC, and appliances.
 - Classrooms rely heavily on natural daylight due to optimized orientation.
 - Midday:
 - The cafeteria prepares meals using solar and biogas-generated electricity.
 - Kitchen exhaust systems are controlled with demand sensors.
 - Evening:
 - Battery storage supplies power for after-school programs, gym lighting, and HVAC loads.
 - Rainy periods:
 - Rainwater barrels fill, micro-hydro produces small amounts of supplementary power, and water is used for irrigation and toilets.
 - Weekend/holiday:
 - The building management system powers down HVAC and lighting zones to minimal levels, reducing phantom loads.
- Energy Balance
 - Buildings consume 30–50% less energy due to insulation, zoning, LED lighting, and passive solar design.
 - On-site renewables generate 100–120% of average energy demand on sunny days, allowing storage or export to the grid (if net-metering is allowed).
- Maintenance
 - Most systems are low-maintenance: solar and wind are monitored via software; the digester and HVAC require periodic checks.
 - LED lights last 10–15 years, geothermal HVAC systems 20–30 years with minimal servicing.

Scalable Pathway for Districts

Step	Implementation Phase
Solar canopies and LED retrofits	Year 1-2
Smart controls + HVAC zoning	Year 2-3
Green roof or solar tracker pilot	Year 3-4
Digester + water reuse loop	Year 4-5
New school construction	Built fully sustainable

With phased rollout, school districts can start small and scale up, building toward the full model in this proposition.

Benefits & Real World Impact:

Summary of Benefits:

- Environmental
 - Near-zero carbon emissions (vs. 2000+ tons/year for a traditional school)
 - Rainwater reuse, reduced stormwater pollution/runoff
 - No fossil fuels are used on-site
 - Zero on-site fossil fuel use
 - Closed-loop water and waste systems
- Educational/Social
 - Healthier indoor air quality(HRVs, native materials), more natural light, and reduced noise
 - STEM integration into the daily curriculum
 - Model for climate action in education
 - Real-time energy data in classrooms
 - Curriculum aligned with sustainability, climate science, and engineering
 - Students engaged in maintaining gardens, compost systems, and solar monitoring
 - Offers all students—regardless of zip code—exposure to clean technology and climate literacy.
- Financial
 - Lower utility and maintenance costs over 20 years
 - Lower lifetime costs despite higher upfront spending
 - Qualifies for tax incentives, bonds, EPCc, and federal IRA rebates

- Upfront cost offset by grants, green bonds, and PPA
- \$150K–300K annual utility + maintenance savings
- Resale and community value increase
- Reduces long-term operating costs, freeing up funds for teachers, programs, and enrichment.

This school is designed to maximize energy efficiency across all aspects—lighting, heating and cooling, power production, and water use.

- Educational & Operational Integration
 - Every system doubles as a learning tool:
 - Real-time energy dashboards in classrooms
 - Students can monitor solar output, wind speeds, and water collection in science, math, or computer science classes
 - STEM Projects:
 - Monitoring solar efficiency, turbine design, and hydro experiments
 - Compost + Digester:
 - Hands-on STEM and environmental science learning; connects biology, chemistry, and sustainability.
 - Rain Garden and Native Plant Zones:
 - Used for environmental science, biodiversity studies, and climate adaptation discussions.
 - Building Management System:
 - Integrated into the curriculum as a real-world example of computer programming, IoT, and data analysis.
 - Sustainability Metrics: Emission reductions, waste diverted, energy self-sufficiency
 - STEM Career Exploration:
 - Engineering, renewable energy, and sustainable agriculture become part of everyday learning.
 - Enhances resilience to blackouts, water restrictions, and climate extremes, keeping schools operational when others might close.

Conclusion:

This renewable-powered school design demonstrates how sustainability, educational innovation, and real-world practicality can be seamlessly integrated into one cohesive model. By aligning energy efficiency with educational goals, the school becomes more than a place of learning; it becomes a living, breathing example of 21st-century thinking — where students engage directly with the technologies shaping their future.

Though the initial investment may be higher, the long-term return is undeniable: lower operational costs, reduced environmental impact, and a generation of students empowered by experience. Scalable across districts, this approach is not just visionary — it's viable. It

transforms schools into dynamic, cross-disciplinary “labs for the future,” where the curriculum extends beyond the classroom walls and into the systems powering the building itself.

In reimagining our schools this way, we’re not just educating the next generation — we’re equipping them to lead.