Noah Korotzer & Ryan Davies
Winter 2026 E[3]

Integrative Design Report: Project Exertricity

1. Introduction

The fitness industry sells a unique service: the **opportunity to do work**. This invites synergy between energy-intensive fitness facilities and its occupants converting chemical to kinetic and thermal energy. Consumers exert effort to move mass or generate heat through rotational friction in cardio exercises. Simultaneously, the facility consumes energy to maintain thermal comfort for their clients, typically using a carbon-intensive grid or natural gas. Put simply, the facility consumes energy to remove energy from a space. We felt this highly inefficient scenario was ripe for the application of integrative design.

As two former collegiate athletes who've spent many hours in gyms, we were inspired to tackle this challenge. We focus on a mid-sized gym to examine decarbonization pathways by reimagining fitness. We show that energy efficiency not only benefits the environment but also significantly reduces operating costs and provides a better experience.

1.1 System Boundaries

We operate in coastal northern California with mild climate and relatively year-round sunshine. Our system boundaries expand beyond the gym's building to include our consumers, equipment manufacturers, holistic fitness experience, and software-integrated membership. First, we identify key needs of our clients:

- Exercise
- Thermal comfort
- Entertainment
- Healthy air and healthy spaces
- Personal hygiene

1.2 Assumptions

We open from 6am—10pm daily. Using mean data from a 2025 industry report[1], our prototypical gym has:

- 4,837 ft^2
- 129 members
- 104 workouts per member per year
- 48 occupants per day[2]
- 20 8-minute showers per day
- Daily occupancy percentages of: 40% morning, 10% mid day, 50% evening

We assume $2.84/MMBtu of natural gas[3], two-tiered electricity price of $0.30/kWh off-peak and $0.60/on-peak, and net-metering configuration. Environmental analysis assumes

[1] Two-Brain Business: The State of the Fitness Industry (2025), https://twobrainbusiness.com/the-state-of-the-industry/
[2] Assuming 104 annual workouts per person yields a daily workout rate of 28%, which when multiplied by 129 members gives 37 members per day. 1 guest per day is assumed.
[3] Using EIA data from 2/21/26 for CA, https://www.eia.gov/naturalgas/weekly/#tabs-prices-2

carbon intensity of 52.9 kg CO_2e/MMBtu for natural gas and 0.24 kg CO_2e/kWh for grid electricity.[4]

We examine three scenarios: baseline, efficient, and moonshot. “Baseline” assumes natural gas for heating and no on-site generation. “Efficient” presents conservative efficiency assumptions while “moonshot” explores potential best-case results—we wouldn’t want to repeat mistakes of projection models by underestimating the energy efficiency resource potential. Our full calculations for each case are shown in **Section 7: Appendix** for brevity.

2. Energy loads

2.1 Baseline energy consumption

For HVAC, we calculate a Pacific West scale factor against national energy consumption averages.[5] We apply that to technology-specific energy usage (MMBtu/m^2) and add body heat cooling, accounting for heat generated through exercise.[6] See appendix for full calculations.

Table 1: Baseline Annual Energy Loads

Load	Annual Demand	Units	Annual kg CO2e	Annual Cost
Space heating (natural gas)	101.15	MMBtu	5,350.96	$287.27
Space cooling (A/C)	4,147.38	kWh	987.08	$1,866.32
Body heat cooling (A/C)	3,722.59	kWh	885.98	$1,675.17
Lighting	8474.40	kWh	2016.91	$2,152.50
Office / entertainment loads	8760.00	kWh	2084.88	$3,942.00
Hot water (showers)	70.01	MMBtu	3703.76	$248.55
TOTAL			15029.56	$10,171.81

2.2 Lighting and Entertainment

To reduce lighting loads we add daylighting through glass garage doors.[7] They open to create open-air space during mild weather, reducing HVAC loads and improving air quality and access to nature.[8] These utilize robust sealing, super-window glass, and well-fitted notches when lowered to prevent air gaps.

Angled shading allows solar thermal energy during the winter but provides shade in the summer (link). Shades are set at a latitude-specific degree angle; automated shades are lowered

[4] EPA greenhouse gas equivalence calculator, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results
[5] EIA Commercial Buildings Energy Consumption Survey (2018), https://www.eia.gov/consumption/commercial/data/2018/ce/pdf/e2.pdf
[6] Conditioned Air Solutions: The Human Factor in HVAC, https://www.conditionedairsolutions.com/blog/the-human-factor-in-hvac/
[7] For example, LuxFit is a fully open-air concept that has enjoyed success in CA. Their system is designed to fit all equipment within shipping containers for storage and easy transport.
[8] E^3 Lecture Videos: Buildings

according to internal facility temperature. In our efficient scenario, this reduces daytime lighting loads by 80%; in our moonshot scenario, it eliminates them entirely.

In addition to daylighting, we reduce plug loads with a master switch controlling office and entertainment equipment (computers, TV's, speakers), reducing loads to zero when unoccupied. Combined with intentional efficient equipment, this reduces annual energy use by 4,380 kWh, saving $1,101.72 in the efficient case and 6132 kWh or $3,274.49 in the moonshot case.

2.3 Hot Water

A key service is personal hygiene solutions—showers—which require hot water. We average 20 8-minute showers daily; each shower consumes 20 gallons. We estimate that 60% of summer-time water requires heating, 85% in winter, and 75% in shoulder seasons. We must heat the water to 135 ℉[9]; summer-time tap water is 60 ℉, 55℉ in winter, and 57℉ in shoulder seasons.[10] By precisely calculating year-round heating needs, we "shrink gaps between actual and theoretical-minimum use, and optimize for integrated and typical conditions while tolerating rare, abnormal ones."[11] Low-flow shower heads reduce 8-minute shower water consumption to 12 gallons, reducing upstream hot water needs. We also deploy a solar thermal hot water system (see **Section 4.1.2**).

2.4 HVAC

In addition to open-air concepts and improved insulation, we decorate our facility with plants that improve indoor air quality and produce oxygen, improving customer experience and reducing necessary air circulation. Some stationary bikes are fan bikes to facilitate air circulation. Thus human work provides air turnover where it is needed most: at the person. Our efficient scenario estimates 70% HVAC reduction met by a 300% efficient heat pump; our moonshot scenario eliminates the HVAC system entirely.

2.5 Total Energy Loads

Table 2: Total Energy Loads

Load	Baseline Annual Demand	Units	Efficient Annual Demand	Moonshot Annual Demand	Units
Space heating	101.15	MMBtu	2,964.49	0	kWh
Space cooling (A/C)	4,147.38	kWh	1,244.21	0	kWh
Body heat cooling (A/C)	3,722.59	kWh	1,116.78	0	kWh
Lighting	8,474.40	kWh	4237.2	3177.9	kWh
Office / entertainment loads	8,760.00	kWh	4,380.00	2628	kWh
Hot water (showers)	70.01	MMBtu	348.07	0	kWh

---

[9] DOE: Estimating the Cost and Energy Efficiency of a Solar Water Heater, https://www.energy.gov/energysaver/estimating-cost-and-energy-efficiency-solar-water-heater
[10] East Bay Municipal Utility District: Water quality data, https://www.ebmud.com/water/about-your-water/water-quality/water-quality-data
[11] Amory Lovins, Creating The Next Energy Revolution: Integrative Design for Radical Energy Efficiency

3. Novel equipment

Traditional exercise equipment generates resistance with weights, friction, air, water, and electromagnetism. Some companies take electromagnetic cardio equipment to its logical conclusion: harnessing generated electric current.[12]

We propose innovative strength-training equipment that replaces weights using the same strategy. However, removing weights creates an issue: instability against motion. Without weights, we need something heavy to weigh equipment down. We flip this into an opportunity using whole-systems thinking: notoriously heavy batteries stabilize our equipment, stabilize energy generated from exercise, and enable additional revenue streams through energy arbitrage. Thus, we integrate energy storage into our core service without occupying functional space.

3.1 Electricity generation

Converting human mechanical work into electricity is no breakthrough—take a WWII handcranked radio, for example—but electricity-generating equipment is usually seen as a gimmick because humans are weak power generators. It'd be nonsensical to pay human generators for the same reason the automobile was invented: machines vastly outperform mammals in energy generation density.

However, we challenge this assertion that workout power is inconsequential by working backward from end-use. We view the generated electricity as **free** because the work **already exists**: people workout regardless of whether you capture that energy or not. The generation actually incurs a **negative cost** because people pay the gym to workout! Even better: gym occupancy peaks in the evening alongside electricity demand. In summary, people pay to workout when energy costs are highest—an exciting synergy.

3.2 Battery integration

We transform batteries' weight—typically a design challenge—into primary function. With batteries integrated directly into equipment, we deploy behind-the-meter energy storage without disrupting members or requiring space. This reduces reliance on grid electricity and unlocks revenue via energy arbitrage, further explored in **Section 4.3**.

A battery's energy density is less important in our use-case than in others. In EVs, degradation inhibits vehicle performance and induces range anxiety. Our integration offers potential to deploy end-of-life batteries from other industries, another synergy and avenue for cost reduction. By converting waste into input, we lower capital costs and support a circular economy.

3.3 Additional benefits

Our novel equipment provides more than generation and storage:

- Electricity-generating equipment is inherently "smart" by measuring power output, enabling automatic workout tracking, analysis, and congestion data for facility optimization.
- Power is an advanced exercise metric—objective, scales with fitness level (unlike calories), and comparable across exercises.[13]
- Weight-less equipment is smaller.
- Weight-less equipment is more easily adjustable and accessible.

[12] SportsArt ECO-POWR ELITE, https://www.gosportsart.com/eliteecopowr/
[13] Equinox: WHY SMART CYCLISTS TRAIN WITH WATTS, https://www.equinox.com/articles/2015/06/how-to-train-with-watts

- Flywheels generate omni-directional resistance, unlike unidirectional weights.

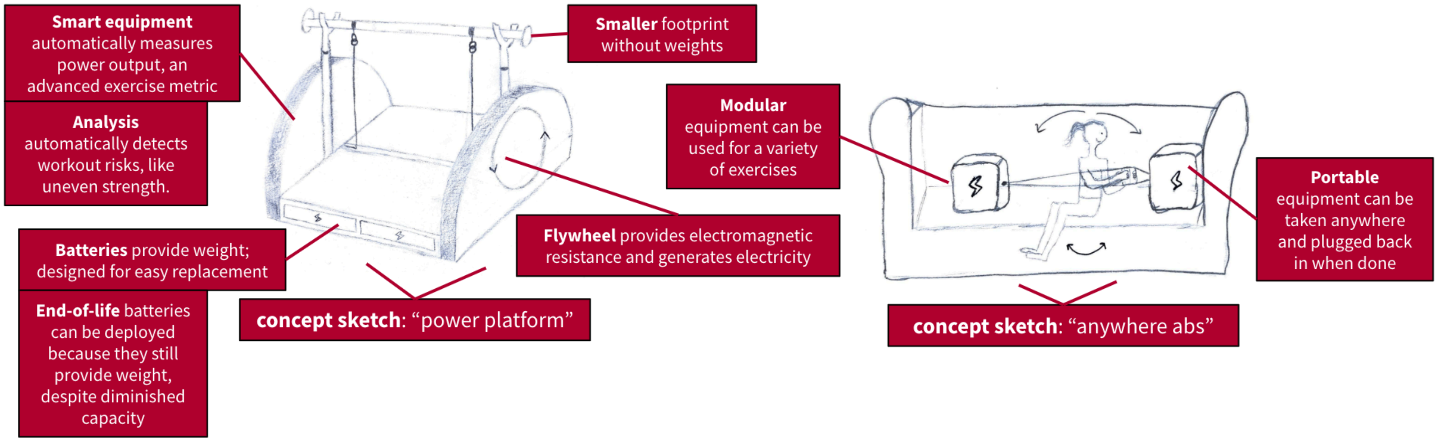

Fig 1: Innovative Exercise Equipment

4. Energy supply

After defining needs and reducing demand, we evaluate generation. Our gym deploys onsite generation—solar and electricity-generating equipment—and behind-the-meter storage via battery integrations. Controller software manages the microgrid as online RL agents learn complex system dynamics in real-time.[14] Our online RL agent optimizes first for fully meeting electrical load without grid electricity and second for maximizing revenue. Thus, our gym learns as it is used, based on measured data and not rules of thumb.

4.1 Solar

Solar, captured three ways, is our primary energy source: daylighting, PV, and thermal. Daylighting, discussed in **section 3.2**, reduces our electrical lighting loads.

4.1.1 Solar PV

Rooftop PV is angled for latitude-specific optimal production. Awning-based PV complements our planned daylighting, shading the building in the summer while simultaneously generating power. We also deploy parking lot canopy PV to achieve a total solar area of 5,000 ft^2. This equates to 70 kW of generating capacity in the efficient and 140 kW in the moonshot scenarios.[15] [16]

4.1.2 Solar thermal

Solar thermal energy is utilized in two ways. In winter months, we limit shading to heat our space. We also produce hot water for showers with solar thermal panels mounted on the remaining roof space to provide 90% of summer-time hot water needs, 70% in winter, and 80%

[14] An Online Reinforcement Learning-Based Energy Management Strategy for Microgrids With Centralized Control, Meng et al. 2024, https://ieeexplore.ieee.org/abstract/document/10603406
[15] Solar Reviews: California Solar Panel Cost in 2025, https://www.solarreviews.com/solar-panel-cost/california
[16] Zero Solar: Understanding Title 24: What You Need to Know About Solar Requirements for New Commercial Buildings in California (2025), https://xerosolar.com/title-24-solar-requirements-new-commercial-buildings/

in shoulder seasons.[17] We don't need electric pumps because the system is roof-mounted. Leftover water heating needs are met using a heat-pump water heater near the gym ceiling. This location allows the heater to capture ambient thermal energy and optionally expel cold dry air to the gym floor, reducing cooling loads. Under our moonshot scenario, solar thermal water heating provides all hot water, removing the need for the heat pump.

Table 3: Solar Energy Generation						
Source	**Efficient Offset (kWh/yr)**	**Efficient Cost savings ($/yr)**	**CO2e savings (kg/yr)**	**Moonshot Offset (kWh/yr)**	**Moonshot Cost savings ($/yr)**	**CO2e savings (kg/yr)**
Solar PV	105,000.00	$47,250.00	24,990.00	210,000.00	$94,500.00	49,980.00
Solar Thermal - Water	9,726.94	$0.00	2,315.01	12,158.67	$4,377.12	2,893.76
TOTAL	114,726.94	$47,250.00	27,305.01	222,158.67	$98,877.12	52,873.76

4.2 Workout waste to worth

Exercise work is currently wasted rather than harnessed; consensus suggests that it's not worth converting into useful work. Evaluating a single workout, this seems true: assuming power output of 250W[18] for 90 minutes, the average workout generates 375 Wh worth approximately $0.09.

However, the impact adds up when aggregated. With 129 members working out 104x/year, this generates 5 MWh annually. In our moonshot scenario, consumer incentives (see **Section 5**) entice 200 members to workout 150x/year and 1500 annual non-member workouts, generating 11.8 MWh—more than the annual electricity consumption of the average US residential home[19]—completely passively (though it doesn't feel so passive).

Table 4: Annual Workout Waste to Worth				
Scenario	**# Workouts**	**Electricity Generated (kWh/yr)**	**Cost savings ($/yr)**	**CO2e savings (kg/yr)**
Base	17,520	0.00	$0.00	0.00
Efficient	17,520	6,570.00	$2,956.50	1,563.66
Moonshot	31,500	11,812.50	$5,315.63	2,811.38

4.3 Energy arbitrage

While batteries provide grid benefits—frequency regulation, reactive power, phase synchronization, millisecond-level responses, and black starts—we focus on energy arbitrage revenue, assuming sufficient transmission capacity. We estimate approximately 1 MWh of

[17] SolarTech: How Do Solar Water Heaters Work? Complete Guide 2025, https://solartechonline.com/blog/how-solar-water-heaters-work/
[18] Princeton: Human Power and Propulsion, https://www.princeton.edu/~maelabs/hpt/pro/human_3.htm
[19] EIA: How much electricity does an American home use? https://www.eia.gov/tools/faqs/faq.php?id=97&t=3

storage and assume that energy arbitrage earns $0.10/kWh daily.[20] In our moonshot scenario, we deploy *less* battery storage by leveraging partially-degraded end-of-life EV batteries to reduce e-waste and our reliance on ethically-dubious supply chains for critical minerals.

Energy arbitrage generates significant revenue, far outweighing energy costs. Not only does our gym gain a competitive advantage, but it also transforms into resilient energy infrastructure, enabling further penetration of variable renewables and facilitating the clean energy transition.

Table 5: Annual Energy Arbitrage Revenue

Scenario	Battery Storage Capacity (kWh)	Efficiency Factor	Daily Revenue ($)	Annual Revenue ($)
Base	0	0.00	$0.00	$0.00
Efficient	1,000	0.90	$90.00	$32,850.00
Moonshot	700	0.90	$63.00	$22,995.00

5. Consumer incentives

People want to protect the environment for current and future generations but don't know how to. They struggle to see how their small actions can help and instead feel powerless and hopeless against climate change.

Our sustainable gym provides consumers with tangible actions woven into their daily lives. We foster a community-oriented environment with education about clean energy, such as real-time monitoring displayed in the facility, similar to Delta Electronics Fremont office lobby screen. We also institute programs that utilize our synergistic design: consumers improve their personal health through exercise and our planetary health by displacing emissions.

Carefully-designed software features encourage more frequent and intense workouts. Combined with sustainability marketing, we gain an advantage in winning market share. In our moonshot scenario, we increase our membership from 129 to 200 and increase annual workouts from 104 to 150. This doesn't require physical expansion because of improved workout density from novel equipment, as discussed in **section 3.3**.

5.1 Incentive programs

Our gym promotes a one-of-a-kind "workout more, pay less" program. We pass some workout-generated value back to members to build loyalty, create unique marketing opportunities, and incentivize members to workout more.

We also institute programs for members to bring friends for free or allow non-members to workout during low-traffic periods. This allows non-members to try our novel exercise equipment, potentially expanding sales.

5.2 Software integrations

We integrate a software platform to offer many benefits. With automatic workout tracking and objective power output measurements, users easily see progress over time and celebrate new achievements.

Users form private groups and join public communities to organize social workouts. Users also set goals—publicly or privately, individually or collectively—and compete in

[20] Note that we define "earning" as the cost offsets the batteries supply, through either discharging to the grid or discharging to the facility, rather than the cost of electricity sold to the grid.

competitions. This could spawn a "creator" community where public figures showcase their favorite power-generating workouts while viewers watch live—or even join virtually alongside them! Similar programs have been successfully deployed by companies like Strava and Peloton.

Gamification, like experience points and dynamic rankings, is a powerful way to alter human behavior. Typically, these techniques create addictions to social media and video games. We leverage gamification to encourage healthy exercise habits and provide energy education while placing safeguards to prevent addiction (e.g. geofenced access). For example, users receive a "2-week power rating" that compares their individual generation to a solar PV cell or their entire team's generation to a small hydroelectric turbine.

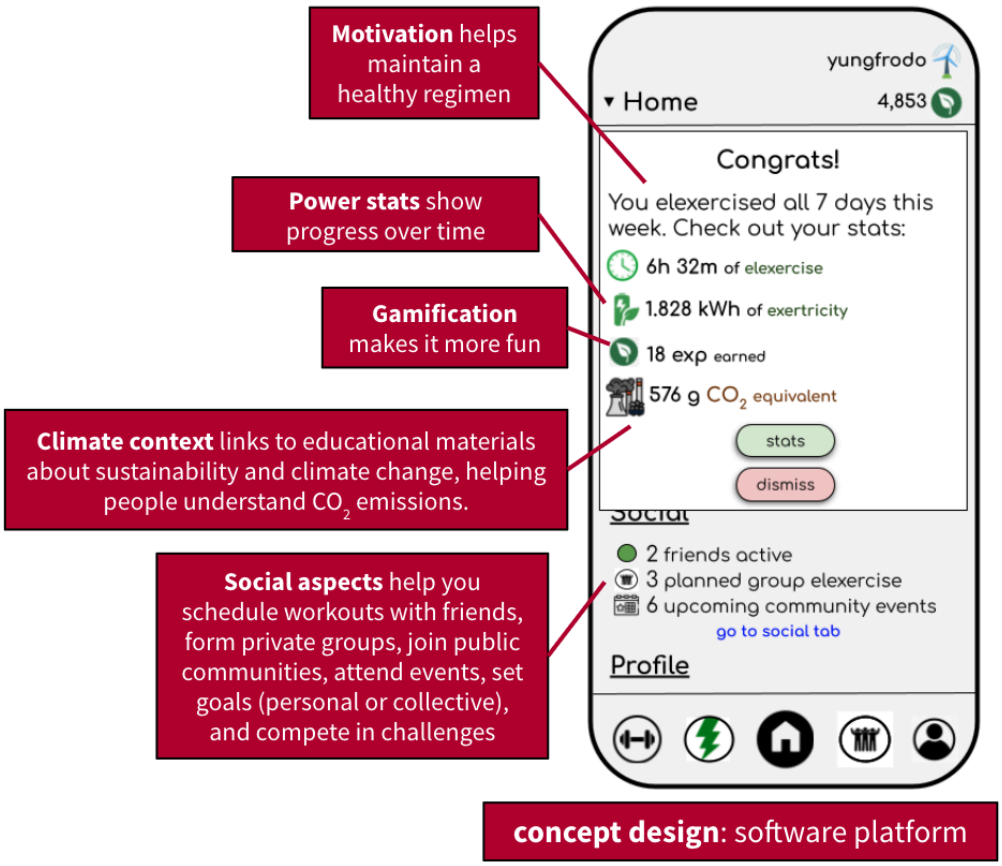

Fig 2: Software Platform Integrations

5.3 Resilience Hubs and Climate Cafés

Gyms with capacity for energy storage and on-site generation have everything else needed to function as a community resilience hub: net-zero HVAC, water, bathrooms, showers, space, basic medical supplies, and urban locations. Our gym would be fully equipped to function as a resilience hub in case of a natural disaster.

Exercise centers are also a great place to connect with community members. Our lobbies would intentionally create space to educate people about sustainability. Our gym would be decorated with indoor plants, which reduce temperature fluctuations, improve mental health, and provide oxygen. We install e-waste collection bins, integrating one more clean energy solution into our member's daily lives. With strained critical mineral supply chains, e-waste collection could become an additional revenue source, similar to companies buying used cooking oil to recycle into sustainable fuels.[21]

6. Conclusion

By approaching the concept of exercise, and the spaces where we exercise, with a beginners mind, we were able to apply integrative design to unique and novel ways, resulting in a redefined fitness experience for all involved. Through the use of novel exercise equipment, thoughtful facility layout, and services focused energy systems we can achieve large cost reductions while delivering a product that is better for the customer, the operator, and the environment. Our final whole system design is best explored visually, through the graphic below:

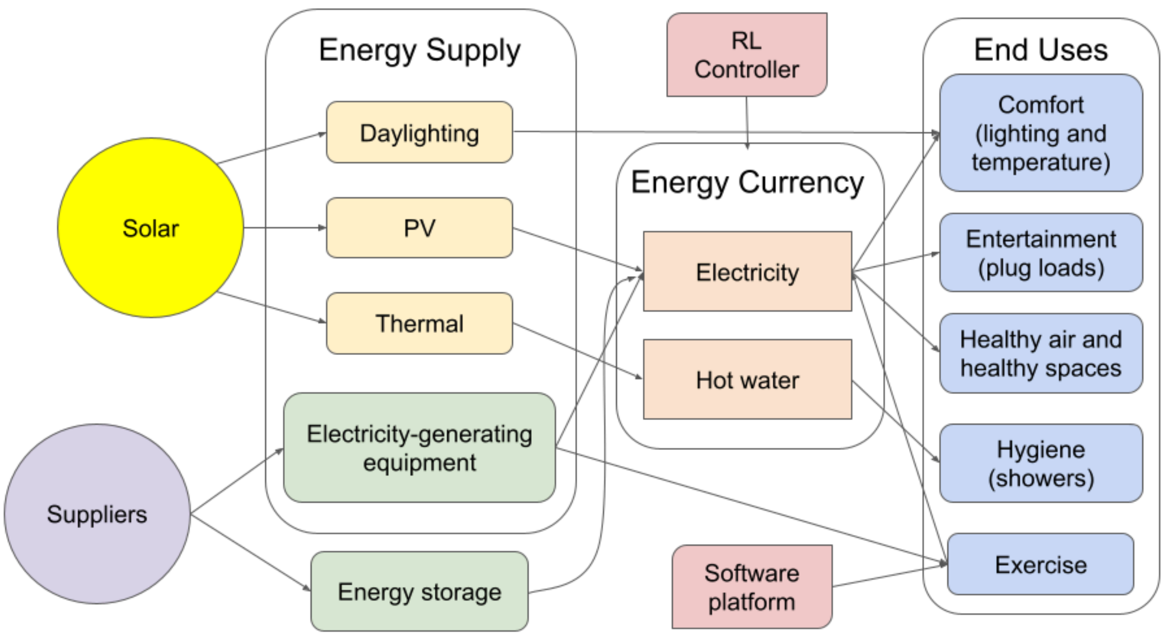

Fig 3: Whole System Design and connection diagram

Table 6 shows full demand and generation calculations for each scenario, and Table 7 shows economic analysis and environmental analysis.

[21] Grand Natural Inc: Used Cooking Oil Collection San Francisco, https://www.grandnaturalinc.com/locations/used-cooking-oil-recycling-in-san-francisco.html

Table 6: Full Scenario Comparison						
Scenario	**Baseline**	**Efficient**	**Moonshot**	**Baseline**	**Efficient**	**Moonshot**
Loads	**Strategy**			**Annual Demand (kWh)**		
Space heating	Natural gas	Insulation; heat pump	Insulation	101.15 MMBtu	2,964.49	0
Space cooling	Electric A/C	Passive cooling; heat pump	Passive cooling	4,147.38	1,244.21	0
Body heat cooling	Electric A/C	Passive cooling; heat pump	Passive cooling	3,722.59	1,116.78	0
Lighting	LEDs	LEDs; 80% daylighting	LEDs; 100% daylighting	8,474.40	4,237.20	3,177.90
Office / entertainment loads	Plug loads	Occupancy controller; plug loads	Occupancy controller; plug loads	8,760.00	4,380.00	2,628
Hot water (showers)	Natural gas	Solar thermal; water heater	Solar thermal	70.01 MMBtu	348.07	0
Generation	**Strategy**			**Annual Generation (kWh)**		
Solar PV	None	Rooftop; awning	Rooftop; awning	0	105,000.00	210,000.00
Solar Thermal	None	Rooftop	Rooftop	0	9,726.94	12,158.67
Equipment	None	Novel equipment	Novel equipment	0	6,570.00	11,812.50
Energy Arbitrage	**Strategy**			**Annual Arbitrage (kWh)**		
Batteries	None	New batteries	Recycled batteries	0	328,500	229,950
TOTAL	N/A			25,104.37 kWh; 171.16 MMBtu	-107006.19	-228165.27

Table 7: Economic and Environmental Comparison						
Scenario	**Baseline**	**Efficient**	**Moonshot**	**Baseline**	**Efficient**	**Moonshot**
Loads	**Annual Cost ($)**			**Annual CO2e (kg)**		
Space heating	$287.27	$1,334.02	$0.00	5,350.96	1,058.32	0.00
Space cooling	$1,866.32	$559.89	$0.00	987.08	259.96	0.00
Body heat cooling	$1,675.17	$502.55	$0.00	885.98	58.26	0.00
Lighting	$2,152.50	$1,906.74	$1,430.06	2,016.91	1,008.45	756.34
Office / entertainment loads	$3,942.00	$1,971.00	$1,182.60	2,084.88	1,042.44	625.46
Hot water (showers)	$248.55	$156.63	$0.00	3,703.76	19.05	0.00
Generation	**Annual Revenue ($)**			**Annual displaced CO2e (kg)**		
Solar PV	$0.00	$47,250.00	$94,500.00	0	24,990.00	49980.00
Solar Thermal	$0.00	$4,377.12	$5,471.40	0	12,158.67	2893.76
Equipment	$0.00	$2,956.50	$5,315.63	0	1,563.66	2,811.38
Energy Arbitrage	**Annual Revenue ($)**			**N/A**		
Batteries	$0.00	$32,850.00	$22,995.00			
TOTAL	$10,171.81	-$81,002.78	-$125,669.37	15029.56	-35265.86	-54,303.33

With 13.15 metric tons CO_2 displaced per gym and 115,047 gyms across the US,[22] the climate impact could scale up to 1.5 million metric tons CO_2 annually.[23] This estimate doesn't include the potential for schools, PT offices & hospitals, and professional sports teams to implement our designs, nor does it factor in global scale. With these in mind, the scale of impact could be exponentially higher.

6.3 Benefits of Integrative Design

Integrative design was key to our process:

1. **Adopt "beginner's mind"**: Eliminating preconceptions of gyms allowed us to reimagine exercise completely.
2. **Be multidisciplinary**: We drew on our expertise not only as engineers but also as athletes and consumers.

---

[22] Energym: Building a Better Future: The Evolution of Environmentally Sustainable Gyms, https://energym.io/blogs/braingains/building-a-better-future-the-evolution-of-environmentally-sustainable-gyms

[23] We acknowledge that this simplified analysis neglects climatic and grid intensity differences, but serves to show the power of scaling this idea.

3. **Start with intent**: Consumer priorities—satisfaction for doing work, thermal comfort, personal hygiene, and clean air—informed design strategies like our engagement plan, HVAC, hot water, and open-air concept.
4. **Work backward from end use**: Our design process embodied principle 4: first we listed core fitness services then worked backwards to incorporate energy reduction, energy efficiency, and finally generation strategies.
5. **Expand system boundaries**: We considered the whole fitness experience and facility energy flow. Helping customers reduce their carbon footprint through exercise creates motivation and engagement opportunities beyond just fitness. Holistically considering energy flows inspired us to develop a novel equipment concept to convert wasted energy into usable electricity.
6. **Optimize systems**: Novel equipment provided a multitude of benefits beyond its core function: electricity generation, power measurement, traffic data, smaller size, and faster adjustment. Its battery provides not only crucial stabilizing mass but also energy storage.
7. **Relentlessly simplify**: We completely removed HVAC in our moonshot scenario.
8. **Use measured data**: We quantified occupancy rates to accurately size our equipment and reduce system size. Equipment directly measured traffic while our RL controller learned from real-time data to optimally meet service needs and maximize revenue.
9. **Strive for perfection**: Our hot water analysis carefully measured temperature requirements for multiple seasons of the year, along with per-shower consumption, allowing us to right-size water heating equipment.
10. **Learn from great design**: Humanity's evolutionary history inspired us: our strength and cardio capacity helped our village survive by hunting/gathering food, traveling long distances, and fighting. Reconnecting exercise with meaning that benefits society and yourself taps into that original satisfaction.

7. Appendix - Calculations

7.1 Annual lighting loads

Baseline = $0.3\,\frac{W}{sf} * 4837sf * 16\frac{hrs}{day} * 365\frac{days}{yr} = 8474.4\,kWh/yr$

Efficient = $(0.3\,\frac{W}{sf} * 4837sf * (10\frac{hrs}{day} * 20\% + 6\frac{hrs}{day}) * 365\frac{days}{yr} = 4237.2\,kWh/yr$

Moonshot = $0.3\,\frac{W}{sf} * 4837sf * 6\frac{hrs}{day} * 365\frac{days}{yr} = 3177.9\,kWh/yr$

7.2 Annual plug loads

Baseline = $1.5\,kW * 16\,hrs * 365\,days = 8,760\,kWh$
Efficient = $1.2\,kW * 10\,hrs * 365\,days = 4,380\,kWh$
Moonshot = $0.9\,kW * 8\,hrs * 365\,days = 2,628\,kWh$

7.3 Annual hot water loads

<u>Baseline</u>

Season	Quantity of end use	Quantity of use

Summer	38 people per day, 20 showers total @ 20 gal per shower = 400 gallons.	Heating from 60 deg f to 135 deg = 75 deg. This is 626 BTU per gallon. Assume 60% of water needs to be heated.
Winter	38 people per day, 20 showers total @ 20 gal per shower = 400 gallons.	Heating from 55 deg f to 135 deg = deg. This is 666 BTU per gallon. Assume 85% of water needs to be heated.
Shoulder season	38 people per day, 20 showers total @ 20 gal per shower = 400 gallons.	Heating from 57 deg f to 135 deg = 78 deg. This is 651 BTU per gallon. Assume 75% of water needs to be heated.

Heating load (Btu) = $400\ gal\ \ *\ 651\ \frac{Btu}{gal}\ \ *\ \ \%\ per\ season$

<u>Efficient</u>

Season	Quantity of end use	Quantity of use	Reduced Demand
Summer	38 people per day, 20 showers total @ 12 gal per shower = 400 gallons.	Heating from 60 deg f to 135 deg = 75 deg. This is 626 BTU per gallon. Assume 60% of water needs to be heated.	Low flow shower heads = 12 gal per shower. Solar thermal meets 90% of hot water demand in summer. Heat pump efficiency assumed as 350%.
Winter	38 people per day, 20 showers total @ 12 gal per shower = 400 gallons.	Heating from 55 deg f to 135 deg = deg. This is 666 BTU per gallon. Assume 85% of water needs to be heated.	Low flow shower heads = 12 gal per shower. Solar thermal meets 70% of hot water demand in summer. Heat pump efficiency assumed as 350%.
Shoulder season	38 people per day, 20 showers total @ 12 gal per shower = 400 gallons.	Heating from 57 deg f to 135 deg = 78 deg. This is 651 BTU per gallon. Assume 75% of water needs to be heated.	Low flow shower heads = 12 gal per shower. Solar thermal meets 80% of hot water demand in summer. Heat pump efficiency assumed as 350%.

Heating load (Btu) = $240\ gal\ \ *\ 651\ \frac{Btu}{gal}\ \ *\ \ \%\ hot\ water\ needed\ per\ season$

Daily energy use (kWh) $= (load\ Btu - (0.9 * load\ Btu)) * \frac{1}{3.5} * \frac{2.9\ kWh}{10000\ Btu}$

- where 3.5 is the assumed heat pump efficiency

Moonshot

Season	Quantity of end use	Quantity of use	Reduced Demand
Summer	38 people per day, 20 showers total @ 12 gal per shower = 400 gallons.	Heating from 60 deg f to 135 deg = 75 deg. This is 626 BTU per gallon. Assume 60% of water needs to be heated.	Low flow shower heads = 12 gal per shower. Solar thermal meets 100% of hot water demand in summer. Heat pump efficiency assumed as 350%.
Winter	38 people per day, 20 showers total @ 12 gal per shower = 400 gallons.	Heating from 55 deg f to 135 deg = deg. This is 666 BTU per gallon. Assume 85% of water needs to be heated.	Low flow shower heads = 12 gal per shower. Solar thermal meets 100% of hot water demand in summer. Heat pump efficiency assumed as 350%.
Shoulder season	38 people per day, 20 showers total @ 12 gal per shower = 400 gallons.	Heating from 57 deg f to 135 deg = 78 deg. This is 651 BTU per gallon. Assume 75% of water needs to be heated.	Low flow shower heads = 12 gal per shower. Solar thermal meets 100% of hot water demand in summer. Heat pump efficiency assumed as 350%.

Heating load = 0, all met by solar thermal.
Daily energy use (kWh) = 0, all met by solar thermal.

7.4 Annual HVAC loads

Space cooling (EIA)
Discount factor = $\frac{4.7}{7.0} = 0.67$

Baseline = $4837sf * 13100\frac{Btu}{sf \bullet yr} * 0.67 \div 3 * \frac{1\ kWh}{3412.14\ Btu} = 4,147.38\ kWh/yr$

Efficient = $4,147.38\ kWh/yr * 0.3 = 1,244.21\ kWh/yr$

Body heat cooling (ConditionedAirSolutions)

Baseline = $48\ \frac{occupants}{day} * 1450\frac{Btu}{occupant \bullet hr} * 1.5\frac{hr}{occupant} * 365\frac{day}{yr} * \frac{1\ kWh}{3412.14\ Btu} \div 3 = 3,722.59\ kWh/yr$

Efficient = $3,722.59\ kWh/yr * 0.3 = 1,116.78\ kWh/yr$

Space heating (EIA)

Discount factor = $\frac{14.7}{25.0} = 0.59$

Baseline = $4837sf * 31900\frac{Btu}{sf \cdot yr} * 0.59 \div 0.9 = 101,152,418.89\ Btu/yr$

Efficient = $101,152,418.89\ Btu/yr * 0.3 * \frac{1\ kWh}{3412.14\ Btu} \div 3 = 2,964.49\ kWh/yr$

7.6 Solar energy

Efficient = $70\ kW * 1500\ kWh\ /\ kW\ installed = 105,000\ kWh/yr$
Moonshot = $140\ kW * 1500\ kWh\ /\ kW\ installed = 210,000\ kWh/yr$

7.6 Human-generated electricity

Efficient = $48\ \frac{occupants}{day} * 365\frac{day}{yr} * 250W * \frac{1.5\ hr}{occupant} = 6,570\ kWh/yr$

Moonshot = $(200\ members * \frac{150\ workouts}{yr \cdot member} + 1500\frac{non-member\ workouts}{yr}) * \frac{250W * 1.5\ hr}{workout} = 11,812.5\ kWh/yr$

7.7 Energy arbitrage

Efficient = $10\ EV\ equivalent * \frac{100\ kWh}{EV\ equivalent} * 0.9 * \frac{\$0.10}{kWh \cdot day} * 365\frac{day}{yr} = \$32,850/yr$

Moonshot = $10\ EV\ equivalent * \frac{70\ kWh}{EV\ equivalent} * 0.9 * \frac{\$0.10}{kWh \cdot day} * 365\frac{day}{yr} = \$22,995/yr$