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# HUMAN POWER GENERATION IN FITNESS FACILITIES

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## ABSTRACT

As energy usage across the world continues to rise, there is a strong need to develop new methods for energy conservation and power generation, particularly approaches that have less environmental impacts. Although human power is not ideal in terms of life cycle costs [1], there are promising application areas for human power in emerging regions where electric power is either not available or not affordable [2]. There is also untapped potential for harnessing human power at most fitness facilities. This paper focuses on the feasibility of capturing this energy at fitness facilities, particularly the Recreational Sports Facility (RSF) at University of California, Berkeley, which averages over 2,800 patrons per day.

In particular, we estimated that patrons using 28 elliptical machines would supply approximately 10,000 kWh into the electric grid over a year. This amounts to only 0.7% of the RSF's total energy needs, but is valuable nonetheless.

An additional benefit in human power generation is its positive social impact. A survey of the RSF users has evinced remarkable enthusiasm for implementing energy generation technology into the facility, both as a power generation tool and as an educational resource. This paper will also address the social benefits of human power generation technology in the gym.

## BACKGROUND RESEARCH

Electricity consumption in the world is rapidly growing. The Energy Information Administration (EIA) predicts that electricity consumption will reach 24.7 trillion kilowatt-hours by 2025. Coal has long been the primary source of energy generation, averaging 50% of total sources [3,4]. However, it can be extremely detrimental to the health of the environment and human population.

As early as 2007, fitness facilities around the world have begun researching applications for converting human power to electricity. The California Fitness facility in Hong Kong was one of the first gym establishments to incorporate human powered machines. Started by French inventor Lucien Gambarota and entrepreneur Doug Woodring, the gym began a program called "Powered by YOU" in which the excess energy generated by members on 13-step cycling and cross-training machines is diverted and converted to power lighting fixtures in the gym [5].

Other gyms in the United States have begun to harness human power as well. The Dixon Recreation Center at Oregon State University (OSU) is one of the many facilities retrofitted between the years 2008 and 2009 by the Clearwater, Florida based company known as ReRev. The company retrofitted 22 elliptical machines at OSU so that the excess energy generated by patrons was diverted to the electric grid. According to the company's website, "An elliptical machine in regular use at a gym using ReRev technology will generate one kilowatt-hour of electricity every two days."

The elliptical machine is the most viable candidate for harnessing human power. As one of the most popular pieces of cardiovascular equipment, elliptical machines provide low-impact exercise that simulates the motion of walking or running [6]. Many modern day ellipticals create training resistance through a permanent magnet eddy current braking system [7]. This system works by creating eddy currents through electromagnetic induction over a set of resistor coils located at the back of the machine. However, users of the machine generate much more energy than is required to provide adequate exercise resistance and this excess energy is currently dissipated as heat. Thus, the motivation for gyms across the nation is to harness this energy to create usable electricity that can be fed back into the electric grid.

Studies on human power potential have revealed human legs are up to four times more powerful than human arms. On average, a human can sustain about 100 W of power through pedaling for an hour but only hand crank about 30 W of power in an hour [8]. Studies also demonstrate that a person's oxygen consumption, and consequently their potential power output, decrease with age, with the peak of potential power output being between 20-40 years of age [9]. Given these findings, retrofitting elliptical machines in university campuses is extremely profitable as it takes advantage of both the power potential of human legs as well as the user's youth.

## METHODOLOGY

This project focuses on the technical feasibility and social benefits of retrofitting elliptical machines such that they can harness and redirect human power to the electric grid. Specifically, 28 elliptical machines at the Recreational Sports Facility (RSF) at the University of California, Berkeley, were considered. The RSF averages about 2,800 patrons a day and spans over 100,000 square feet of basketball courts, weight rooms, and cardiovascular machine rooms. An analysis of the energy consumption of the facility, the potential energy that could be harnessed from retrofitting the machines, the cost-benefit and the social impact of such a retrofit was performed.

## ENERGY CONSUMPTION OF THE RSF

Annual electricity data from the academic years 1986-2009 are displayed in Figure 1. It shows that the average energy consumption of the facility is about 1.6 million kWh per year. Of these years, the peak was approximately 1.76 million kWh in the 1996-1997 academic year, followed closely by a 1.7 million kWh usage in the 2007-2008 academic year; the minimum was about 1.45 million kWh in the 2008-2009 academic year. The largest decrease in energy consumption was a 17.5% drop of 253,840 kWh between the years 2007-2008 and 2008-2009, in spite of the fact that five additional business hours per week were added at the RSF during this period.

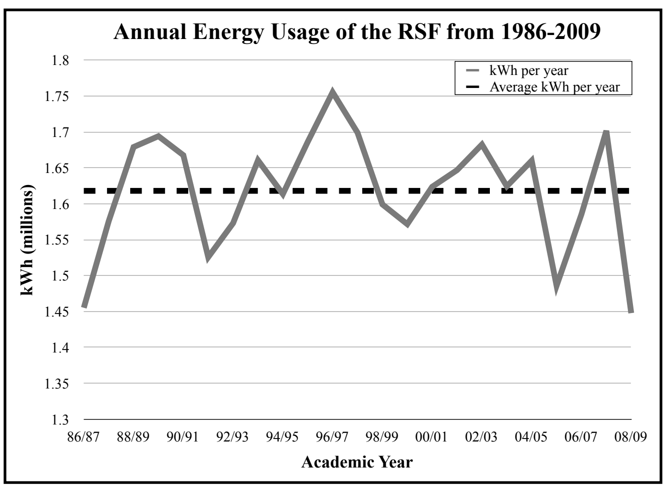



**FIGURE 1: ANNUAL ENERGY USAGE OF THE RSF FROM 1986-2009**

During 2008 and 2009, the RSF underwent a massive lighting retrofit. Most of the preexisting light fixtures, such as metal halide bulbs, were replaced with more energy efficient bulbs and many areas were equipped with motion sensors to reduce the use of lights in unoccupied rooms. This retrofit has reduced the energy consumption due to lights by an estimated 25%, from about 730,000 kWh in 2007-2008, to about 580,000 kWh in 2008-2009 [10]. Custodial hours were also recently changed such that cleaning occurs during the RSF's operating hours, thus allowing the facility to be entirely shut down every night.

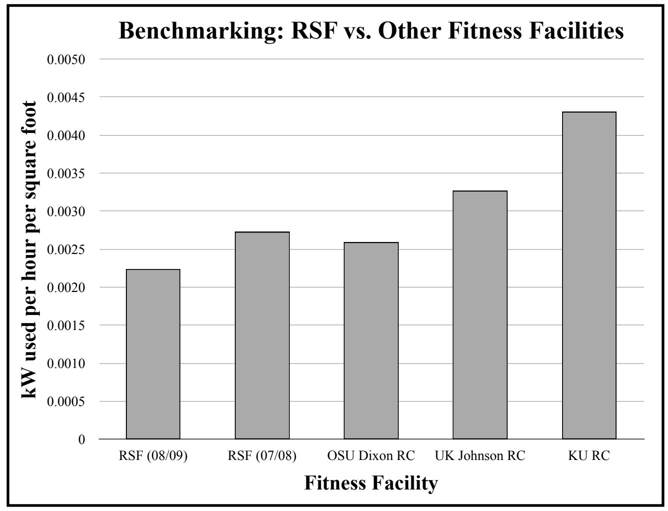
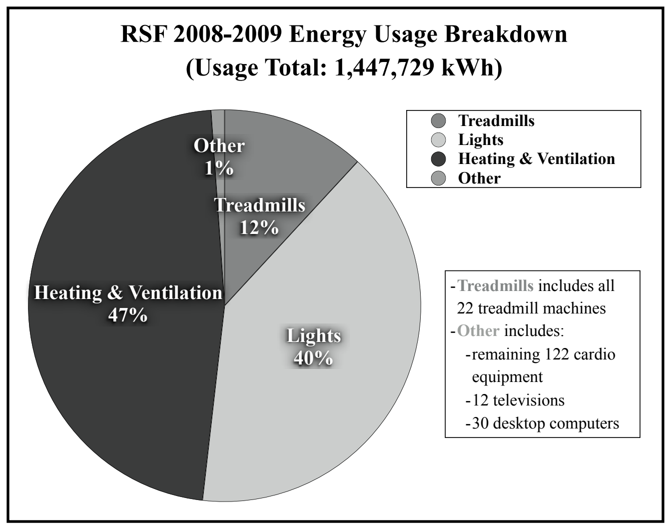



**FIGURE 2: BENCHMARKING: RSF VS. OTHER FITNESS FACILITIES**




Comparing the 2008-2009 energy consumption of the RSF to that of the Oregon State University Dixon Recreational Center (OSU Dixon RC), the University of Kentucky Johnson Recreational Center (UK Johnson RC), the University of Kansas Recreation Center (KU RC), and the 2007-2008 energy consumption of the RSF, on a kWh per square foot per hour basis reveals that the RSF in the 2008-2009 year consumed the least amount of energy, as shown in Figure 2. This is probably due to the absence of an air cooling system at the RSF, combined with the recent lighting retrofit project.

Energy data from the 2008-2009 academic year are presented in Figure 3. An energy audit done on the RSF reports that lighting consumes 40% of the electricity, heating and ventilation consumes 47% of the electricity, and treadmills consume 12% of the electricity. Energy consumption of lights was calculated using the rated energy consumption of all the fixtures in the facility and their approximated yearly burn times, about 580,000 kWh for the 2008-2009 academic year.

Treadmills account for a large portion of the electricity consumption of the RSF due to their mechanical design. Treadmills are operated by a motor that turns a belt on a board that people run on. The velocity of the runner must match that of the belt moving beneath them, in the opposite direction. Treadmills are rated on a scale based on the horsepower (hp) of the motor they utilize and can range from 1.5-3 hp. Thus, a treadmill rated at 3 hp may consume approximately 2.2 kW to provide a one-hour workout for an individual. The RSF currently has 22 treadmills of which half are generally in use at any time. By approximating the average energy consumption of these treadmills to be 1.2 kW per hour per machine, it was calculated that the treadmill machines were responsible for about 170,000 kWh of energy consumption over the 2009-2009 academic year.

By using Kill-A-Watt meters (electrical usage monitors that measure the electrical usage of any device) on all of the other pieces of cardiovascular equipment at the RSF, all the fans, additional powered air vents, computers and monitors, it was estimated that these items only consumed only about 20,000 kWh in total over the 2008-2009 academic year.

Energy consumption of the RSF's heating and ventilation (HV) system was estimated to be the remaining 680,000 kWh of the facility's 2008-2009 energy consumption. This is about 47% of the total energy consumption of the RSF, which falls in line with the HVAC end use energy consumption in commercial buildings in the USA of 48%, according to data from the EIA's 2007 Commercial Buildings and Energy Consumption Survey (CBECS) [11].

## POTENTIAL ENERGY HARNESSING

The RSF currently has 28 elliptical machines that can be retrofitted into energy harnessing devices. The modification entails replacing the current built-in resistance mechanism with a DC/AC micro-inverter. The patron still feels the same machine resistance, but this inverter would now convert the patron's direct current into usable alternating current for the electric grid.

Elliptical machine usage was closely monitored for one week during the month of July 2009. Figure 4 details the possible energy generation. On average, fourteen machines were in use at any time of any day of the week. This number varied a great deal during the week due to weekly gym user trends, as depicted in Figure 5. For instance, Sunday typically has the lowest patronage and averages eleven machines in use. Conversely, Mondays have the highest patronage, with an average of seventeen machines in use. Based on the average elliptical use per day of the week, the average human power producing potential of 100 W for an hour, the number of hours the RSF is open each day, and a harnessing and conversion system efficiency of 85%, it was originally estimated that 7,800 kWh could be harnessed per year using all 28 elliptical machines.

However, after reviewing the annual usage of the RSF for the academic year 2008-2009 displayed in Figure 6, it was noted that July, and the summer months (June, July, August) in general are unusually low periods in the usage of the RSF. This is because there are far fewer students in the Berkeley area during summer break. Considering that the observational data of elliptical machine use were taken at a period of low facility usage, the 7,800 kWh figure is considered to be an approximate minimum of the energy that can be harnessed from the elliptical machines at the RSF. Seeing as the daily gym usage during the summer months is about 2,186 people while the annual average daily usage is approximately 2,825 people, the usage of the facility during the summer is 29% less than the average. Therefore, after scaling the potential energy harnessing data of 7,800 kWh up by 29%, a new estimate shows that retrofitting 28 elliptical machines at the RSF could potentially harness about 10,000 kWh per year.

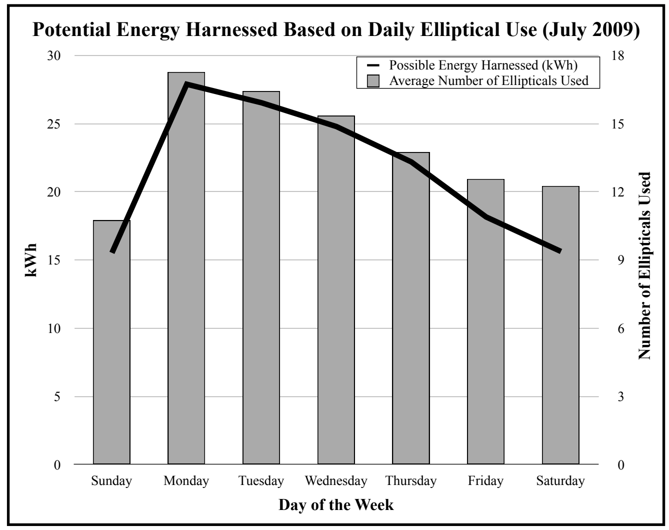



**FIGURE 4: POTENTIAL ENERGY HARNESSED BASED ON DAILY ELLIPTICAL USE (JULY 20009)**

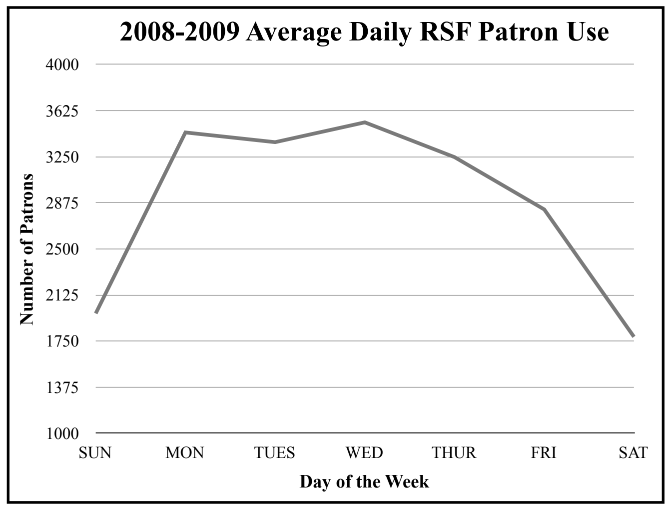



**FIGURE 5: 2008-2009 AVERAGE DAILY RSF PATRON USE**

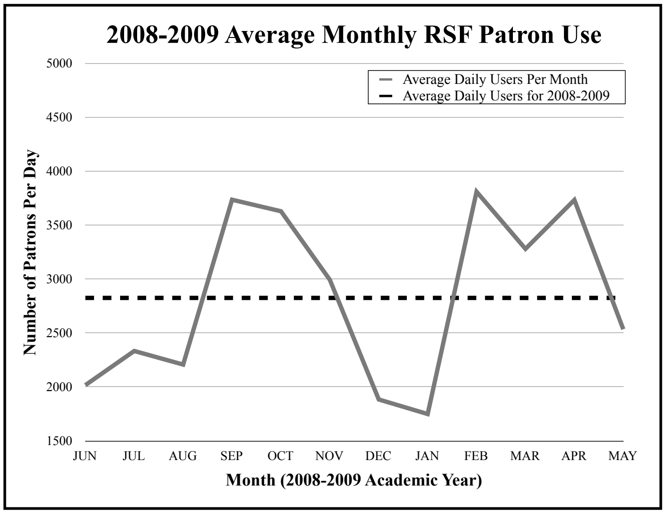



**FIGURE 6: 2008-2009 AVERAGE MONTHLY RSF PATRON USE**

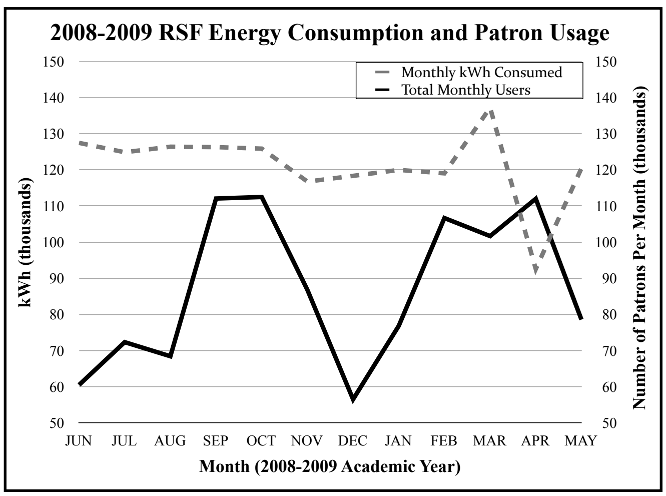



**FIGURE 7: 2008-2009 RSF ENERGY CONSUMPTION AND PATRON USE**

It is also interesting to note that the monthly energy consumption of the RSF is not correlated to the monthly patron use of the facility, as depicted in Figure 7. Thus, in some months in which energy consumption is particularly low while patron usage is high, such as April, the ellipticals could potentially harness 1% or more of the RSF's energy needs. Due to such physical limitations as a limit of one person using an elliptical machine at a time, the absolute maximum energy that can be harnessed is approximately 15,470 kWh a year, which is about 1.1% of the energy consumed by the RSF in the 2008-2009 academic year.

## COST-BENEFIT ANALYSIS

Given that retrofitting the elliptical machines at the RSF can result in harnessing approximately 10,000 kWh per year, based on the 2008-2009 energy consumption of the facility of 1.45 million kWh, the energy harnessed amounts to 0.7% of the energy consumed by the RSF. When analyzing the cost-benefits of retrofitting 28 elliptical machines, it was assumed that the RSF will continue to purchase elliptical machines regardless of the retrofit project, therefore the cost of retrofitting 28 elliptical machines only encompasses the amount needed to purchase additional parts to convert the machines into energy harnessing devices. Considering that the facility pays a relatively low cost for electricity, varying from $0.085 to $0.105 per kWh, the energy harnessed would amount to about $1,000 in yearly savings.

Approximating the cost of retrofitting the machines to be $20,000, the installation would pay itself off financially in about 20 years. However, the average cardiovascular machine at the facility is replaced every 5-7 years, which would mean the retrofitted machines would be retired before the money saved from their harnessed energy could pay off the cost of their retrofit. Thus, from a strictly economic standpoint, retrofitting exercise machines does not seem economically sustainable unless the retrofit hardware could be reapplied to the new machines. Furthermore, assuming a discounted rate of 10%, the true financial payback time would be well over 30 years. However, this analysis did not take into account the inflation rate of energy, which, when considered, may lower the payback time of the retrofit.

**TABLE 1: COST-FINANCIAL BENEFIT ANALYSIS OF RETROFIT**

| | |
|---|---|
| Potential Energy Generated | 10,000 kWh |
| Current Energy Cost | $0.10 per kWh |
| Annual Savings | $1,000 |
| Estimated Cost of Installation | $20,000 |
| Financial Payback Time | 20 years |
| True Payback Time | > 30 years |

Economic analysis of the retrofit further details that, assuming a discount rate of 10%, the present value of the total savings from the retrofit after 5 years would be approximately $3,800. Therefore, the actual cost of retrofitting these machines (present value cost minus the present value of total savings after 5 years) would be about $16,200.

**TABLE 2: PRESENT VALUE ECONOMIC ANALYSIS OF RETROFIT**

| | |
|---|---|
| Total Cost of Retrofit | $20,000 |
| Annual Savings | $1,000 |
| Present Value of Savings after 5 Years | $3,800 |
| True Cost of Retrofit | $16,200 |

## LIFE CYCLE ASSESSMENT

In conducting a Life Cycle Assessment (LCA) on the proposed retrofit of 28 elliptical machines, it was assumed that operation and maintenance of the machines after retrofit would be identical to that before retrofit. Additionally, a one-to-one ratio was assumed between the amount of energy generated and the amount of energy produced by the power plant. For example, it was assumed that producing 10,000 kWh annually at the RSF amounts to reducing the amount of power produced by the power plant by 10,000 kWh annually.

According to PG&E's 2008 Corporate Responsibilities Report, on average 0.00037 metric tons (MT) of carbon dioxide are emitted per kWh of electricity produced [12-15]. Given that the RSF, like other buildings on the University of California, Berkeley campus, purchases its electricity from PG&E, generating 10,000 kWh at the RSF would result in reducing the average yearly $CO_2$ emissions of the facility by approximate 3.7 metric tons (MT). Over the minimum lifetime of a machine (5 years), this would equate to a savings of 18.5 MT of $CO_2$.

The parts used in the retrofitting of the machines consist mainly of AC/DC micro-inverters, electrical wiring and components, and DC-DC converters. Retrofitting the 28 elliptical machines at the RSF is estimated to cost $20,000. Thus, using Economic Input-Output Life Cycle Assessment (EIO-LCA) method [16], $20,000 of economic activity in the "Miscellaneous electrical equipment manufacturing sector" amounts to approximately 9.9 metric tons of $CO_2$ emissions. Therefore, by this measure, the $CO_2$ emissions from retrofitting the elliptical machines at the RSF could be reclaimed in less than 3 years by the energy generated from the installation.

**TABLE 3: LIFE CYCLE ASSESSMENT OF RETROFIT**

| | |
|---|---|
| Potential Energy Generated | 10,000 kWh |
| CO2 Emitted from Purchased Energy | 0.00037 MT per kWh |
| CO2 Saved Annually by Installation | 3.7 MT |
| Minimum CO2 Saved over Lifetime of Machine (5 years) | 18.5 MT |
| CO2 Emitted to Manufacture Additional Parts Required to Retrofit Machines | 9.9 MT |
| Time to Reclaim CO2 Emissions | 2.7 years |

## SOCIAL IMPLICATIONS AND BENEFITS

While from a financial standpoint this installation does not seem like a viable option, there are many social benefits to installing a human power generation center at the RSF. Intrinsic motivation can result in more power generation for longer periods of time [4]. Many of the recreational facilities that have retrofitted exercise equipment to harness human power have claimed to do so not for economic benefits but for social ones. OSU states that they retrofitted their

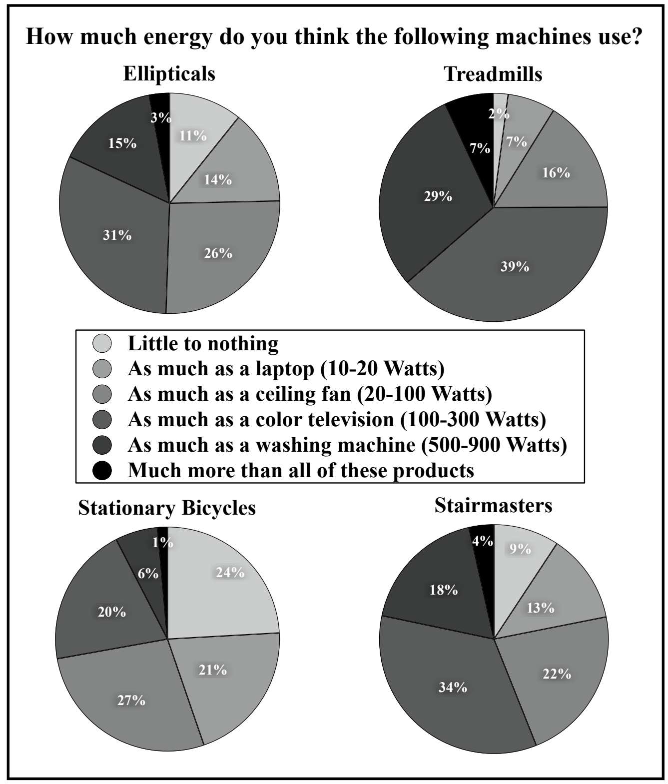



**FIGURE 8: RSF MEMBER SURVEY RESPONSES OF EQUIPMENT ENERGY USE**

elliptical machines because of the social benefits they provide, perhaps motivating more people to go to the gym while also making a statement on sustainability. Demonstrating that people can accomplish something while taking time off their schedule to stay fit has made many patrons happy.

In order to gauge the personal motivation that harnessing human power at the RSF could have as well as other social implications and benefits, a survey was sent out to over 22,000 members of the RSF in late August, during the peak of the RSF usage, to which over 560 people responded. Figure 8 displays the results of the questions regarding the energy consumption of various pieces of equipment. This data indicate that many members could be educated on the energy consumption of various pieces of equipment. For example, 76% believe the stationary bicycles use at least 10 W, when, in fact, the stationary bicycles are self-powered and use no external energy. In addition, many people do not know the energy consumption data of the treadmills, which can be up to 2.2 kWh per hour per machine. Educating members about the "greener" machines in the gym could potentially lead to more sustainable exercise choices, such as exercising on a machine that uses less energy or no energy at all instead of running on a treadmill.

Members were also asked how much energy they believe they could generate; the results are displayed in Figure 9. The data indicate that only about 30% of the members of the RSF gauged the potential human power output correctly, about 20-100 W, while another 34% believed they could produce much

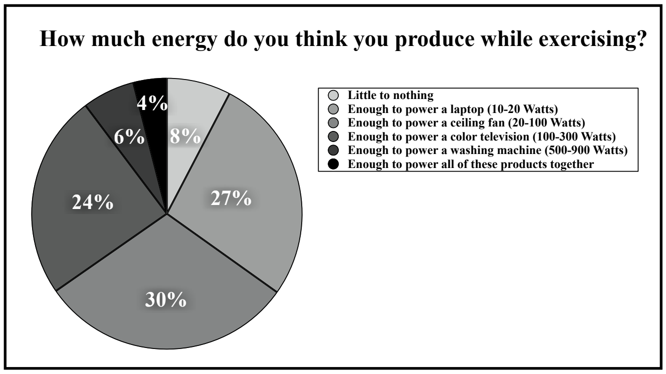



**FIGURE 9: RSF MEMBER SURVEY RESPONSES OF POTENTIAL ENERGY PRODUCTION**

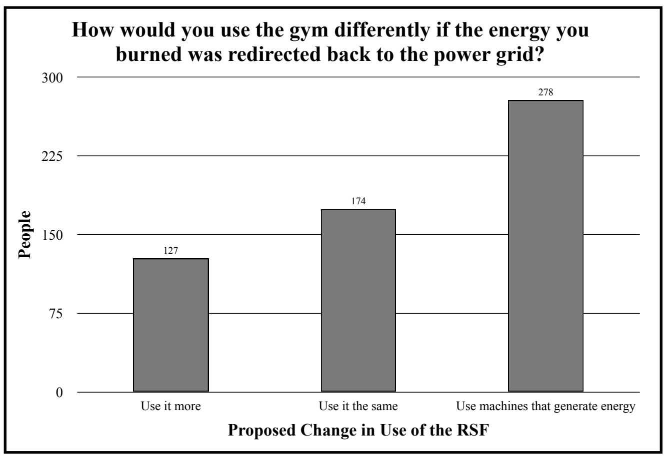



**FIGURE 10: RSF MEMBER SURVEY RESPONSE OF CHANGE IN USER HABITS DUE TO ENERGY HARNESSING INSTALLATION**

more energy than this and 35% believed they would produce much less energy than this. This lack of intuitive knowledge on human power demonstrates that there is also an opportunity for members to be educated on the amount of power humans can feasibly generate.

Finally, Figure 10 displays the member responses of how they would react to an energy harnessing installation at the gym. The data demonstrate that while members may not use the gym more, they would prefer to use the energy generating equipment. If members chose alternative machines instead of treadmills, the energy consumption of the RSF could be further reduced by 170,000 kWh annually, resulting in a savings of $17,000 and 62.9 MT in $CO_2$ emissions.

Many members commented with great enthusiasm about such an installation, with comments such as "why something like this had not already been done" and saying this retrofit would give them "a better reason to workout." Retrofitting the elliptical machines along with educating members on the energy consumption of general exercise machines could therefore have great positive impacts on membership of the RSF, leading to more sustainable exercise options and incentives to exercise.

While an energy education campaign could be launched in the absence of a costly retrofitting project, the RSF survey implied that, if certain machines were converted to harness human power, the majority of users would chose to use machines that generate energy (Figure 10). Additionally, the interactive experience that the human power generation installation provides is integral to the positive user experience. Generating power gives users instant results of their workout where physical effects such as weight lost take much longer. Thus, generating power provides some small amount of instant gratification for users.

## CONCLUSION

This paper describes the technical feasibility and social benefits of human power generation technology in the Recreational Sports Facility (RSF) at the University of California, Berkeley. Considering that the energy consumption of the RSF has already been decreasing due to sustainable measures on the part of the RSF administration such as lighting retrofits, and considering that the RSF is the most energy efficient fitness facility when compared to many others in the nation, it seems that the next step in being a sustainable facility is to invest in alternative energy sources readily available. One such source is human power.

Given that elliptical machines are best suited to be retrofitted into energy harnessing devices due to their mechanical configurations, and the fact that the RSF has 28 elliptical machines that can be retrofitted, it was calculated that approximately 10,000 kWh a year could be harnessed from such a retrofit. This amounts to 0.7% of the RSF's 1.45 million kWh energy consumption in the 2008-2009 academic year.

After considering a cost-benefit analysis on the investment of retrofitting 28 machines, it was found that the energy harnessed from the machines would pay off the cost of installation in 20 years, not an economically feasible amount of time given that cardiovascular machines such as ellipticals are generally retired from the RSF after 5-7 years. However, a $CO_2$ analysis of the installation reveals that the $CO_2$ emissions used to retrofit the machines could be reclaimed by the energy they harness in less than 3 years.

Given the public nature of the exhibit in a large educational institution, there are additional social benefits to pursing the installation of a human power generation center at the RSF. The social implications of retrofitting the machines are pressing reasons to pursue the installation. A survey of the members of the university gym demonstrated that there is a great need for educating members on the energy usage of various pieces of equipment as well as the potential of human power. The survey also demonstrated immense enthusiasm from the student body for the project, many claiming it gave them more motivation to work out. This represents a great learning opportunity on energy and technology literacy for the general student population. Furthermore, if users make more sustainable exercise choices rendering the treadmills obsolete, the energy consumption of the RSF could be further reduced by 170,000 kWh annually, a savings of 62.9 MT of CO2 emissions annually.

Therefore, while implementing human power generation technology in fitness facilities such as the Recreation Sports Facility at the University of California at Berkeley may not be an economically sustainable venture, it is technically feasible, sustainable in terms of CO2 emissions, and the social benefits of such a project are more than enough to push forward with retrofitting the 28 elliptical machines at the facility.

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## REFERENCES

[1] Jansen, A. and Stevels, A., 2006, "Combining eco-design and user benefits from human-powered energy systems, a win-win," *Journal of Cleaner Production*, 14 (15-16), pp. 1299-1306.

[2] Cyders, T. and Kremer, G. G., 2008, "Engineering Around the World: Driving Local Economics in Africa with Human Power," ASME Paper no. IMECE2008-67696, *Proceedings of the ASME 2008 International Mechanical Engineering Congress and Exposition (IMECE2008),* **Vol. 9**: Engineering Education and Professional Development, pp. 181-187.

[3] Hutchison, F. H., 2007 "Facts About Electricity," *Clean-Energy.us: News and Facts about Coal Gasification.* <http://www.clean-energy.us/facts/electricity.htm>.

[4] "Electricity Consumption (most recent) by country," *NationMaster.com: World Statistics, Country Comparisons.* <http://www.nationmaster.com/graph/ene_ele_con-energy-electricity-consumption> compiled based on data from "The World Fact Book," *Central Intelligence Agency*, December 2003-2008.

[5] Gerard, J., 2008 "The Green Gym," *Fitness Matters,* American Council on Exercise, Vol. 14, pp. 12-14.

[6] Miller, L. D., "Elliptical Exercise Device." US Patent 6398695. 4 Apr. 2001.

[7] Whang-Tong, J. et al., "Crosstraining Exercise Device." US Patent 6939271. 6 Sept. 2005.

[8] Dean, T., 2008, *The Human-Powered Home: Choosing Muscles Over Motors.* New Society Publishers, Philadelphia, PA, pp. 64, Chap. 2.

[9] Wilson, D. G., 2004, *Bicycling Science*, 3rd. Edition., MIT Press, Boston, MA, Chap. 2.

[10] March 2007 Lighting Audit of the University of California, Berkeley Recreational Sports Facility. Conducted by Bart Wallace, Certified Lighting Efficiency Professional (CLEP), Certified Energy Manager (CEM).

[11] Energy Information Administration, Commercial Buildings Energy Consumption Survey (CBECS), U.S. Department of Energy, 2007.

[12] PG&E Corporation, 2008 Corporate Responsibility Report.

[13] Pacca, S. and Horvath, A., 2002, "Greenhouse Gas Emissions from Building and Operating Electric Plants in the Upper Colorado River Basin," *Environmental Science & Technology*, 36 (14), pp. 3194-3200.

[14] Varun, I.K., and Bhat, R.P., 2009, "LCA of renewable energy for electricity generation systems–A review," Renewable and Sustainable Energy Reviews, 13 (5), pp. 1067-1073.

[15] Yamada, K., 2008, "Life Cycle Assessment of Electricity Generation in terms of CO2 Emissions: An LCA of Electric Power in Japan," Paris, France.

[16] Carnegie Mellon University Green Design Institute. (2008) Economic Input-Output Life Cycle Assessment (EIO-LCA), US 1997 Industry Benchmark model [Internet], Available from: <http://www.eiolca.net> Accessed 1 December, 2009.