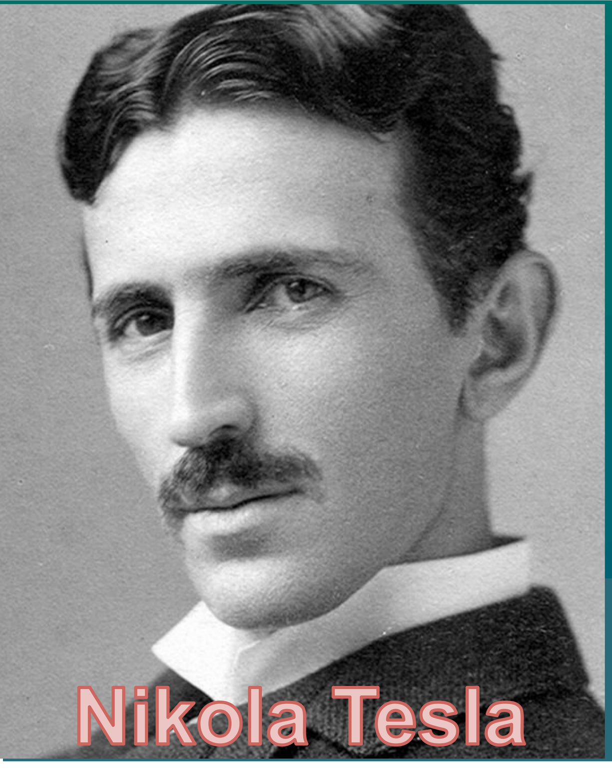
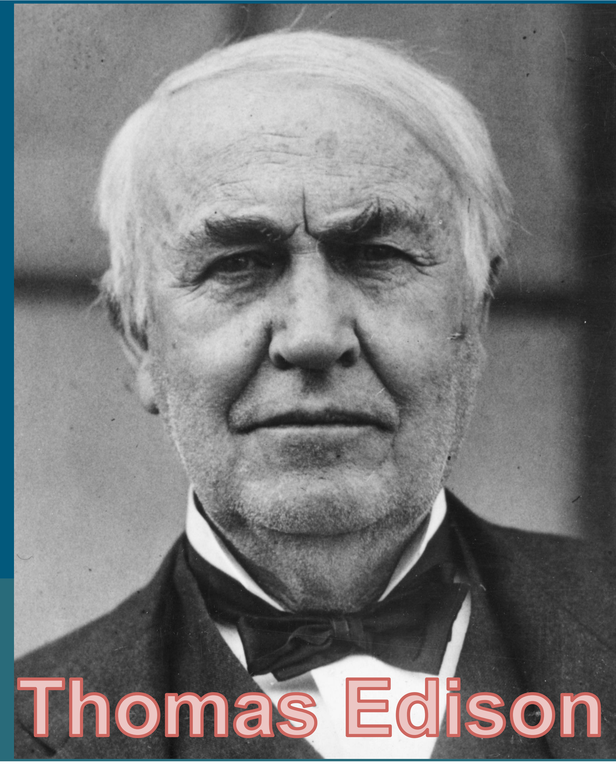


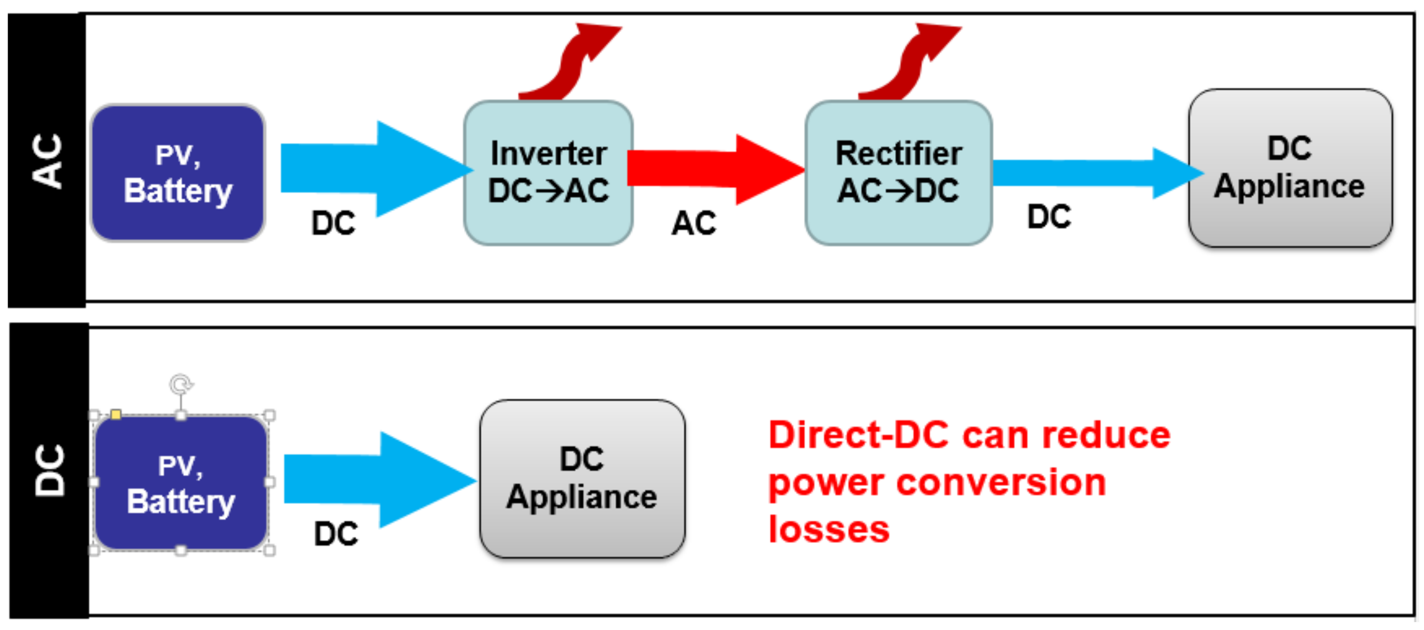
DC Power Distribution in Commercial Buildings



Why DC?

Technology and Market Trends

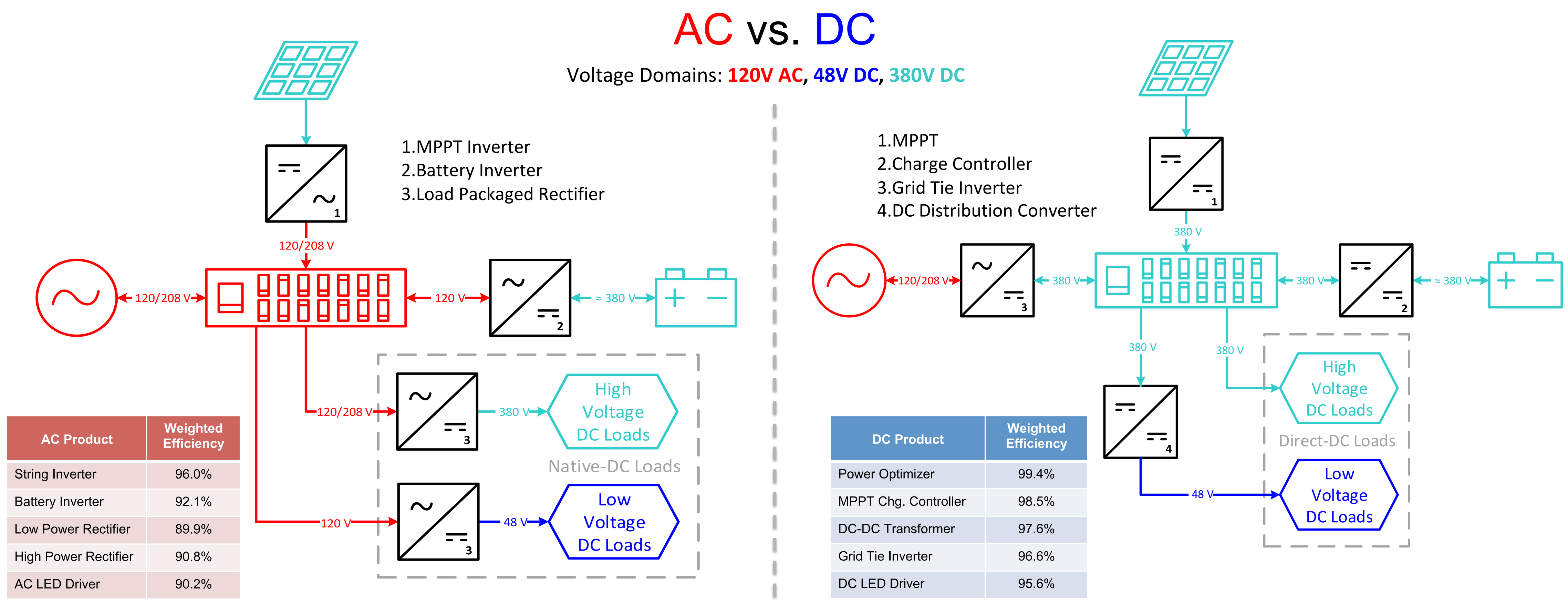
- DC-based distributed generation such as photovoltaic and wind
- On-site DC battery storage
- The most efficient types of loads are natively-DC (LEDs, electronics, EV charging, induction stoves, and variable speed motors in HVAC and water heating)
- Power electronics
- DC Power Standards: USB, Ethernet
- Communications



Potential Benefits

- Energy Savings in Zero Net Energy (ZNE) Buildings with large solar and storage capacity
- Simpler power electronics: better cost and reliability
- Simpler microgrid islanding allows for low-cost disaster resiliency
- Improved power quality
- Combined data and power allows for communications

Analysis Approach



AC Product	Weighted Efficiency
String Inverter	96.0%
Battery Inverter	92.1%
Low Power Rectifier	89.9%
High Power Rectifier	90.8%
AC LED Driver	90.2%

DC Product	Weighted Efficiency
Power Optimizer	99.4%
MPPT Chg. Controller	98.5%
DC-DC Transformer	97.6%
Grid Tie Inverter	96.6%
DC LED Driver	95.6%

Energy Simulation

- Develop Modelica models of AC and DC medium office building in Los Angeles
- Solar profiles from PV Watts, and load profiles from EnergyPlus, and converter efficiency curves from product data
- Use parametric simulations to determine when DC is beneficial and by how much

Techno-Economic Analysis

- Determine first cost difference through product data and estimated quantity
- Determine operating cost from the energy simulation and CA electricity tariffs
- Estimate economic benefits of DC distribution with life cycle cost (LCC) and payback period (PBP)

Experimental Load Modification

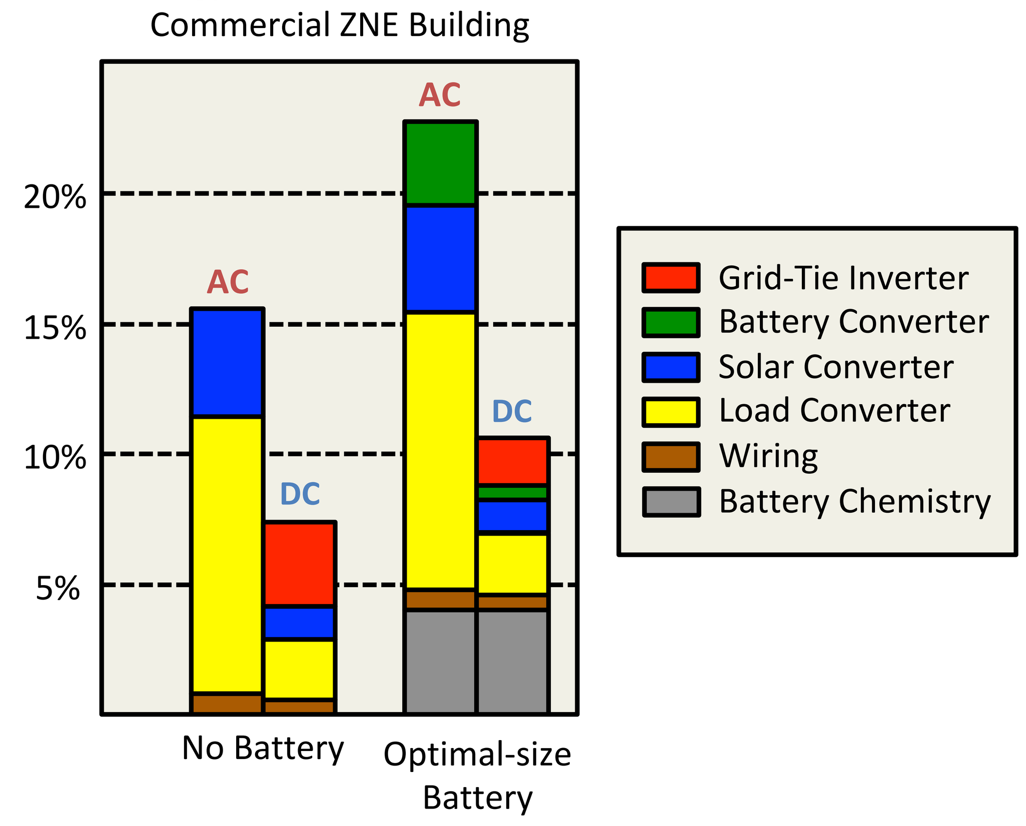
- Modify common AC plug loads for a DC input
- Measure efficiency savings with DC
- Determine how each type of load should be modified to benefit most from DC

Results

Energy Simulation

- 12% baseline efficiency savings with DC
- More savings with high solar and battery capacity
- AC building loss is dominated by the poor efficiency of **load packaged rectifiers**
- DC building loss dominated by the **grid-tie inverter**

Energy Loss for Medium-Size Commercial ZNE Building



Techno-Economic Analysis

- Results determined from market cost data, grid tariffs, and Monte-Carlo analysis
- First cost is higher for DC
- Given the enormous efficiency savings, the payback period is less than a year
- End-use costs, installation costs, and other soft costs not considered

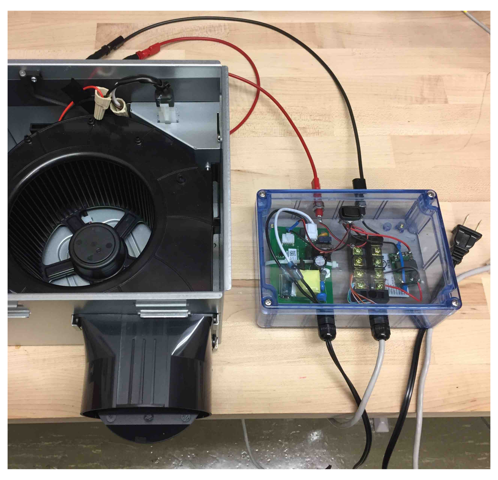
Description	Network	Average LCC Savings (US$)
Total First Cost ($)	AC	252,000
	DC	301,000
Net Annual Electricity Consumption (kWh/yr)	AC	177,000
	DC	101,000
Average LCC Savings ($)	AC vs. DC	61,000
% Cases with Net Benefit	AC vs. DC	>90%
Average Payback Period (yr)	AC vs. DC	~1

$$\mathrm{LCC} = \text{First Cost} + \sum_{y=1}^{\text{Lifetime}} \frac{\text{Operating Cost}(y)}{(1+\text{Discount Rate})^{y}}$$

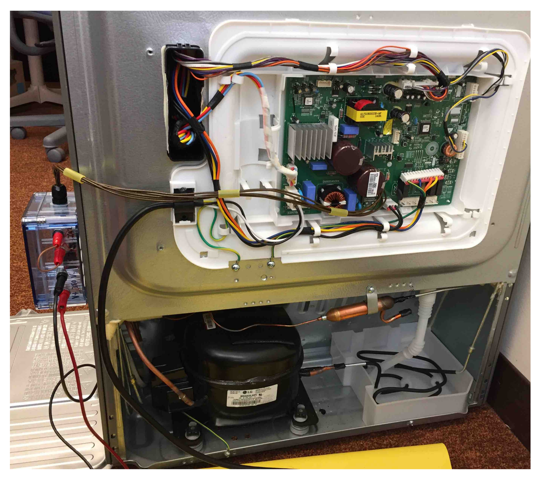
$$\text{Payback} = \frac{\text{First Cost}_{\text{DC System}} - \text{First Cost}_{\text{AC System}}}{\text{Operating Cost}_{\text{AC System}} - \text{Operating Cost}_{\text{DC System}}}$$

Experimental Load Modification

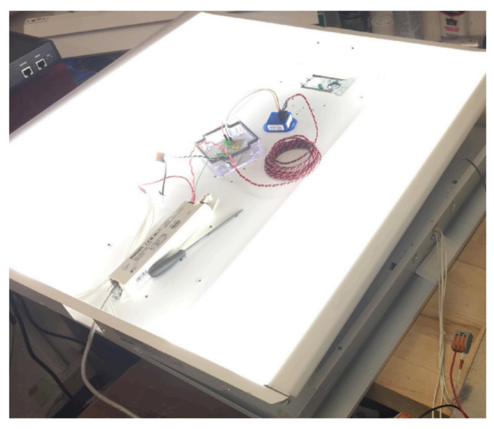
- Modified AC loads to take a DC input
- Demonstrated savings with DC input



Bath Fan (12%)



Refrigerator (1%)

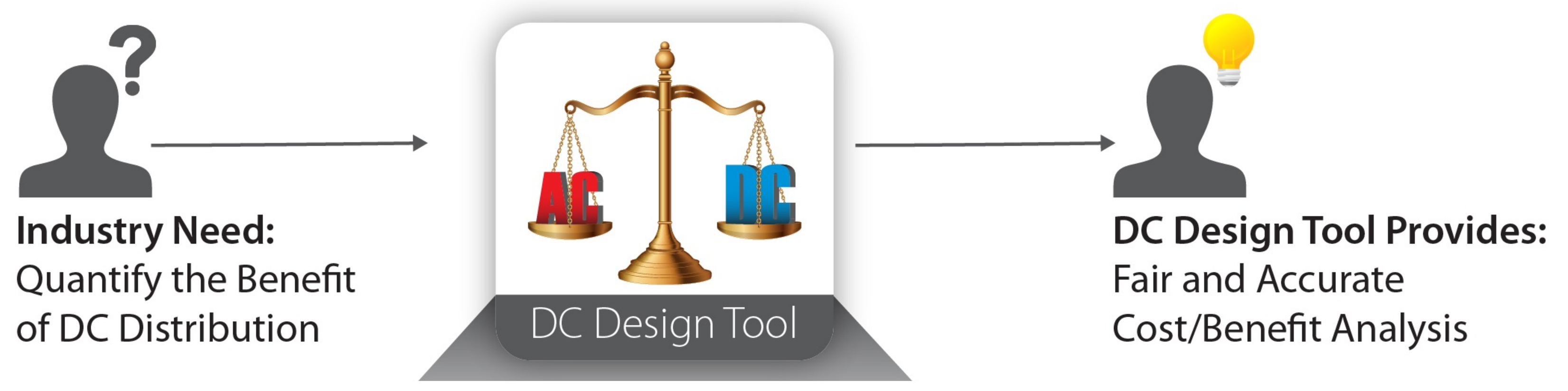


LED Fixture (5%)

LED Zone Lighting (7%)

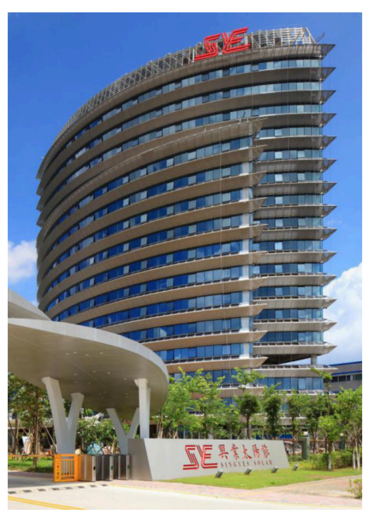
Future Research

- Develop detailed converter loss models to help compare AC and DC
- Develop a DC Design Tool to help building designers compare
- Field test upcoming and developed DC buildings



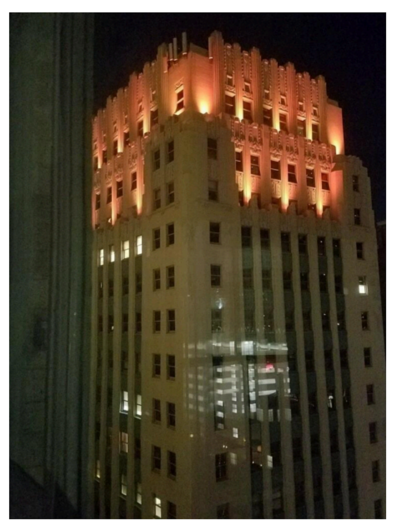
Industry Need: Quantify the Benefit of DC Distribution

DC Design Tool Provides: Fair and Accurate Cost/Benefit Analysis



Xingye Solar Shenzhen

IBEW Building San Leandro



Marriott Sinclair Fort Worth

IBR Building Shenzhen

BERKELEY LAB

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