Design of an Energy Self-Sustained Building

Researchers: Landon Roberts and Martin Goes

Faculty Advisor: Mark Florida

Department of Engineering, Design, and Society (EDNS)

Problem Statement and Goals

Problem: Buildings drive **76%** of U.S. electricity consumption, and that percentage is continuing to grow due to HVAC and water heating electrification incentives [1].

Goal: Create an energy and water use balance for a self-sustained building that minimizes the required energy and water consumption. Make informed decisions for the building layout, materials, energy sources, and water processes to ideally accomplish a net-zero building design.

Method: Use software to calculate energy and water loads, while also performing hand-calculations to verify results.

Original Constraints and Modules

The design analysis relied on the following specifications:

1. **20 x 2000-sq-ft** living spaces for **4** people each
2. **100-sq-ft** office spaces for **20** people
3. Office / living space air temperature remains at **70°F**
4. **100%** LED lighting, All-electric chiller, boiler, and water heater
5. Typical Meteorological Year (TMY) weather data
6. Costs, schedule, and economics do not drive design

A framework for building design used these modules:

1. Calculate Energy and Water Loads
2. Perform Resource Assessments to Meet Loads
3. Design Building Layout to Maximize Energy Production
4. Choose Materials and Appliances that Minimize Energy Load
5. Utilize Graywater Processes to Reduce Water Consumption

While annual water loads were reduced, building design was based primarily on minimizing energy loads and maximizing solar, wind, and geothermal supply capacity.

Data Collection and Modeling

Open-source databases and software used to perform load calculations and resource assessments included:

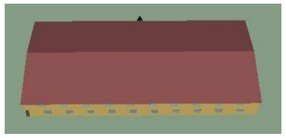
NREL Transforming ENERGY → REopt, System Advisor Model, BEopt → EnergyPlus

U.S. DEPARTMENT of ENERGY → NSRDB & WRDB

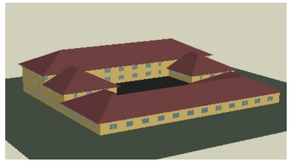
Building Design Process and Methodology

The following notable designs were created in BEOpt to minimize thermal loads and maximize energy production for the building:

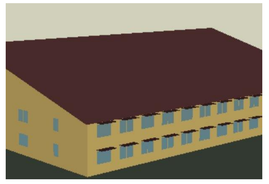
Iteration 3:
- All-electric HVAC and water heating
- Roof pitch = **8°** north-south
- **30%** south-facing wall is windows
- South-facing roof is solar
- **14-ft** apart **300-W** wind on north pitch

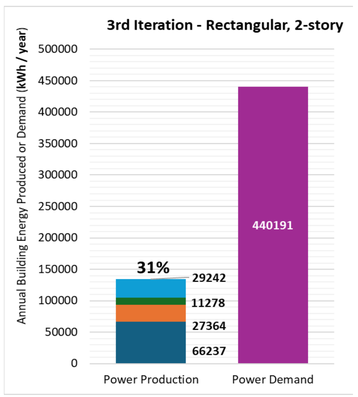


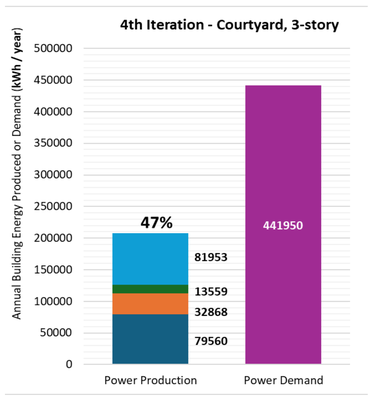
Iteration 4:
- Maximize south-facing windows
- Roof pitch = **18°** north-south
- Demand response heat / cool
- Largest land cover for maximum GHP

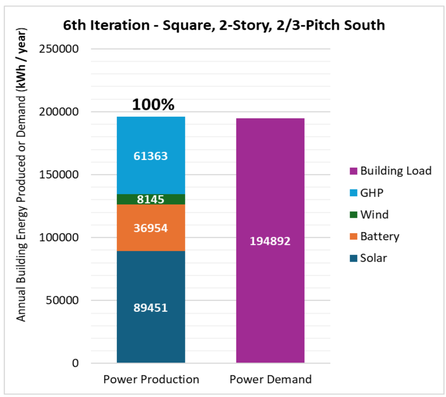


Iteration 6:
- **3-ft** window overhangs: passive solar
- **50%** south-facing wall is windows
- Square roof: **2/3** south-pitch

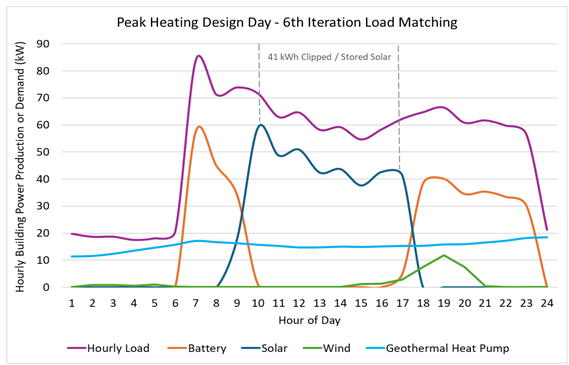


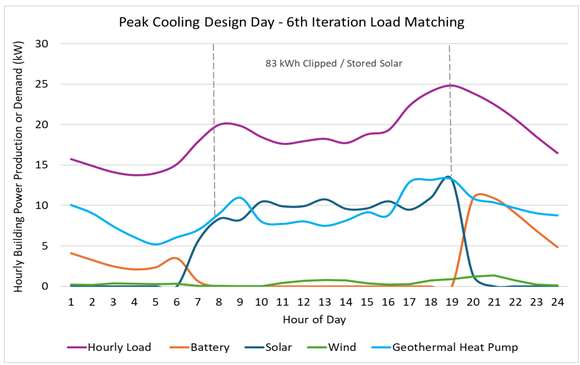






Hourly Energy Use Mapping on Net-Zero Building

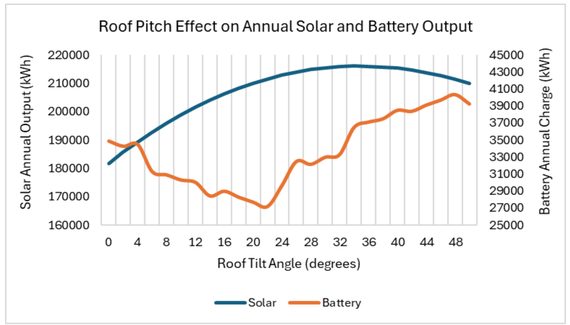




Design days (**January 7** for heating and **July 8** for cooling) were used to model hourly load profile and validate source control logic.

Other Key Takeaways

- **3.6%** increase in annual solar from **18°** {maximum International Building Code (IBC)} to **34°** (optimum output)
- Minimum load-shifting from solar to battery at **22°** roof tilt [2]



Other properties that contributed most to load reduction:
- Insulation (**R-39** Batt Wall, **R-30** Cellulose Ceiling, **R-20** XPS Slab)
- Low-emissivity, non-metal, U-value = **0.29**, triple pane windows
- Cooling: **70°F** setup to **76°F** (in residences during weekday 9-5)
- Heating: **70°F** setback to **64°F**

Next Steps and Application

Considering a hybrid multifamily/office building as "off-grid" is a helpful tool to design for net-zero and measure the feasibility of self-reliance, where a building consumes no energy from the grid, but produces all energy and water within the property lines.

Next steps for the project include:
- Apply a simple economic model to make design choices between the load capacity of each energy source and all building materials
- Estimate system losses over the payback period for the building
- Reduce power clipping by modeling a net-metering control system
- Create a framework for other students to follow the same methodology on different buildings in other locations around the U.S.

Resources and References

[1] "Data for Buildings Sector innovation," U.S. Department of Energy.
[2] "System Advisor Model – SAM," National Renewable Energy Laboratory – NREL.
[3] "REOPT: Renewable Energy Integration and Optimization," NREL.
[4] "BEOPT: Building Energy Optimization Tool | Buildings," NREL.
[5] "National Solar Radiation Database," NREL.
[6] "Wind Resource Database," NREL.
[7] "V-Air | Hoyi 300," Beijing Urban Green Energy.
[8] Ecovie Water Management | Greywater systems for large buildings.