

# Factory-Built, Modular Apartment-in-the-Loop Integration Research Platform

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## Vision:

**Create a marketplace to grow U.S. manufacturing of zero energy ready, technology-integrated, modular apartment buildings**

## Objectives:

- Utilizing apartment-in-the-loop research capabilities in DOE's Energy Systems Integration Facility, create a modular apartment technology development platform that enables the cost-effective design, optimization, prefabrication, and operation of all-electric zero energy, technology-integrated factory built buildings.
- Leverage module development platform to develop and demonstrate novel efficiency and renewable energy technology integration into the multifamily sector both locally and nationally, including hardware, control, and tenant interfaces.

## The Market Opportunity:

- 38 million people live in apartment buildings in the US<sup>1</sup>
  - Large urban growth with a need for affordable housing
- Efficiency efforts in multifamily could save \$3.4 Billion annually<sup>1</sup>
- Energy efficiency and renewable energy integration and innovation in the multifamily sector has been difficult
  - Split incentives
  - Lowest possible first cost approaches
  - Large PV system limitations



## Leverage Modular Apartment Benefits to Enhance EE and RE Opportunities:

### Faster Time to Occupancy:

Modular construction is considerably faster than building from the ground up. Developers and contractors can assemble modular, fully furnished units in factories around the US and ship them to the site ready to install. Shorter project completion times mean units can be rented out sooner, which means a faster return on investment. The first version of the ESIF Modular apartment project was able to rent out faster than site built, allowing \$200,000 of additional collected rent because the project completed 6 months faster than typical site construction.

### Energy Efficiency and Cost Effectiveness:

Factory built modular apartments have much higher quality, as construction materials never see the outdoor environment. Factory quality controls also mean efficiency strategies are installed per specifications- insulation is quality installed, and advanced strategies that require additional expertise can be installed with confidence that would not be present in site built projects. Additional **efficiency costs can also be managed by factory assembly line mass production.**

### Invest in U.S. Manufacturing:

Urban areas need cost effective apartments to accommodate growth in U.S. cities. Many of the modular factories in the US are in industrial and rural areas that are looking to revitalize their manufacturing base and have qualified and available trades.

## Modular Apartment Development

### 2016: 40 Apartment Eliot Flats in Denver

- Proof of concept for factory built module
- Fully metered to baseline end uses and tenant use type distributions
- Base level of efficiency with small PV system for common areas



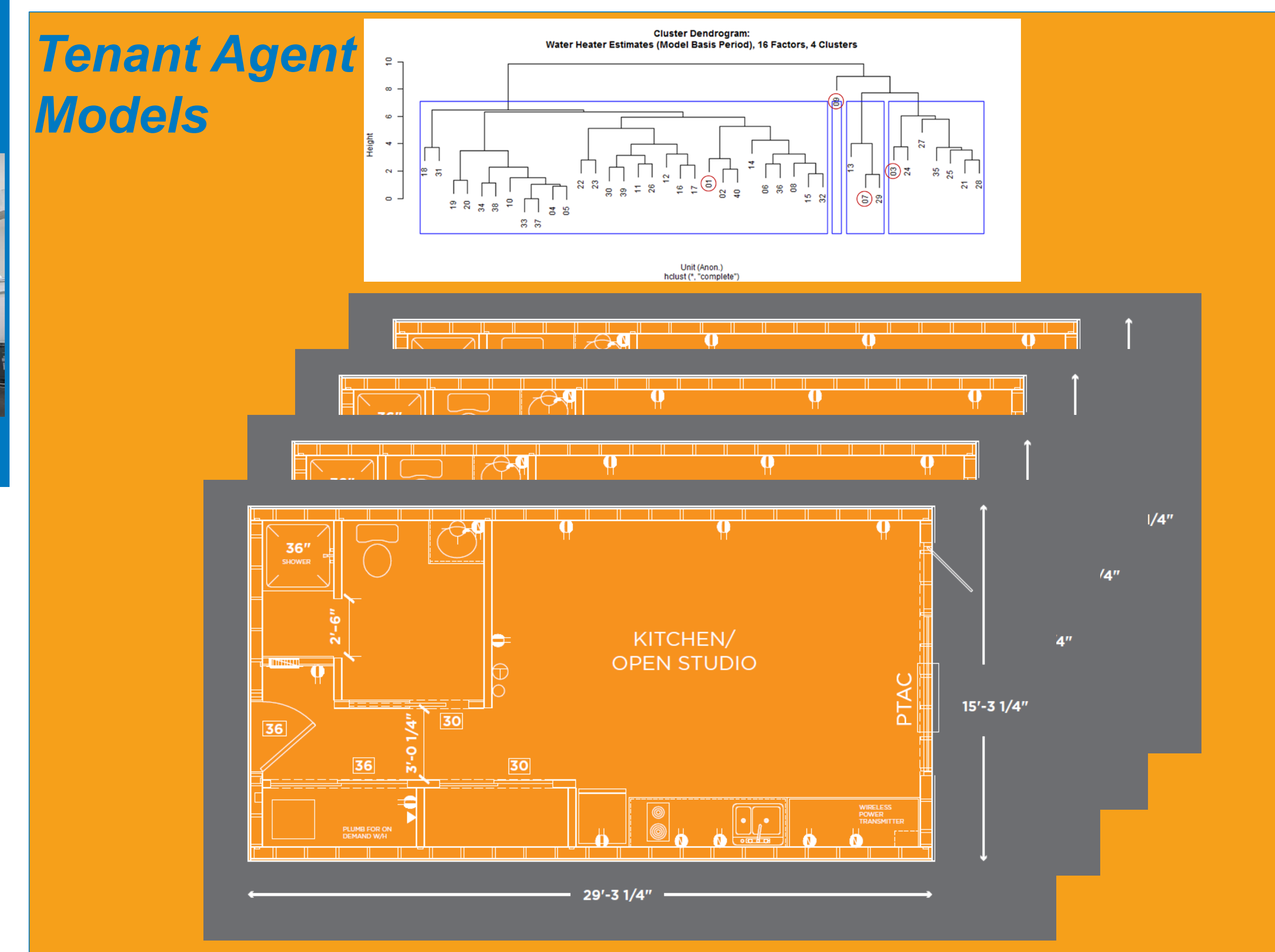
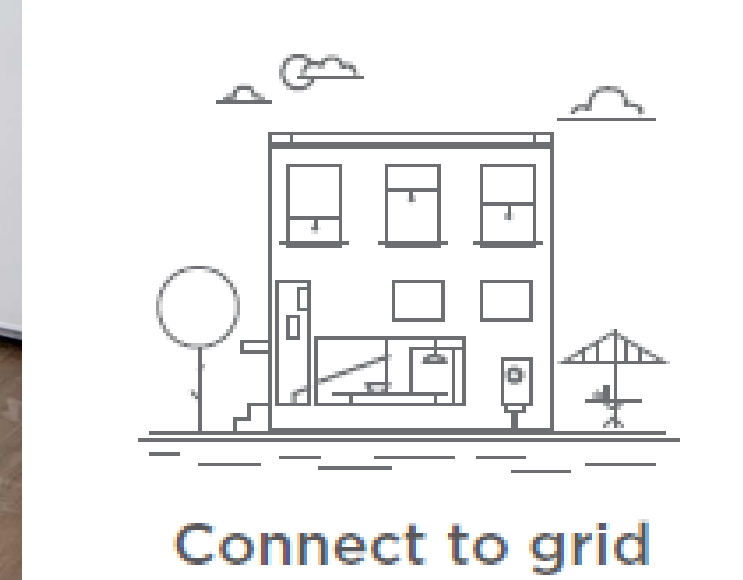
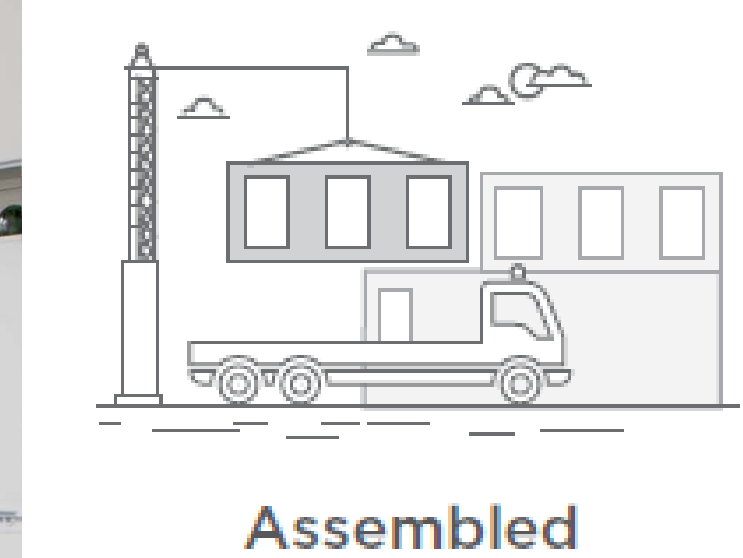
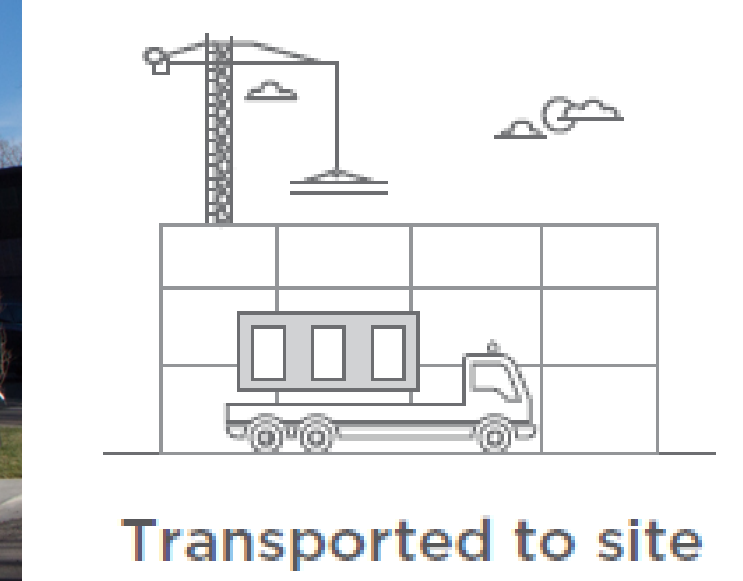
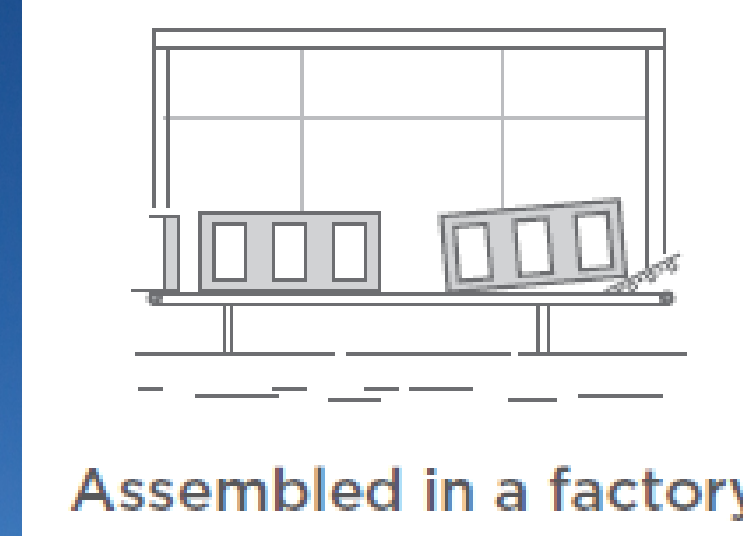
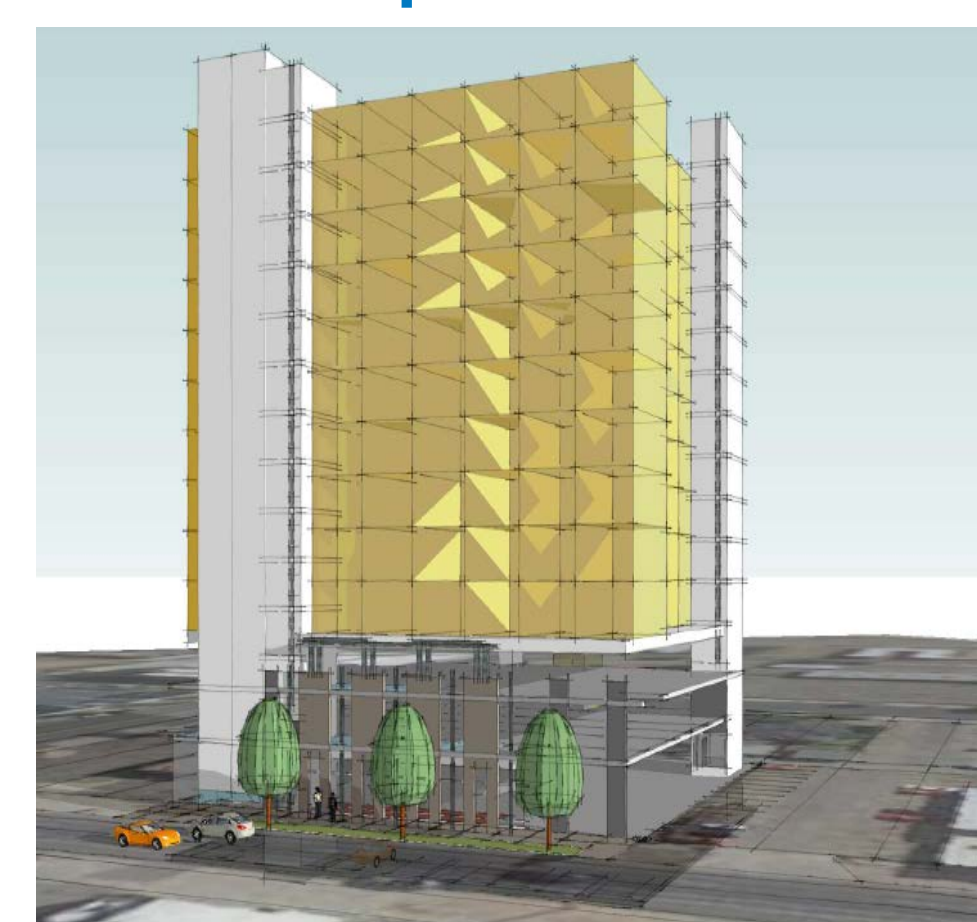
### 2017: Install Prototype Modular Apartment in ESIF

- Integration research platform to optimize factory built module design, technology, and operation
- Scale prototype module to building scale
- Developed solutions to be implemented in next development and to the multifamily marketplace

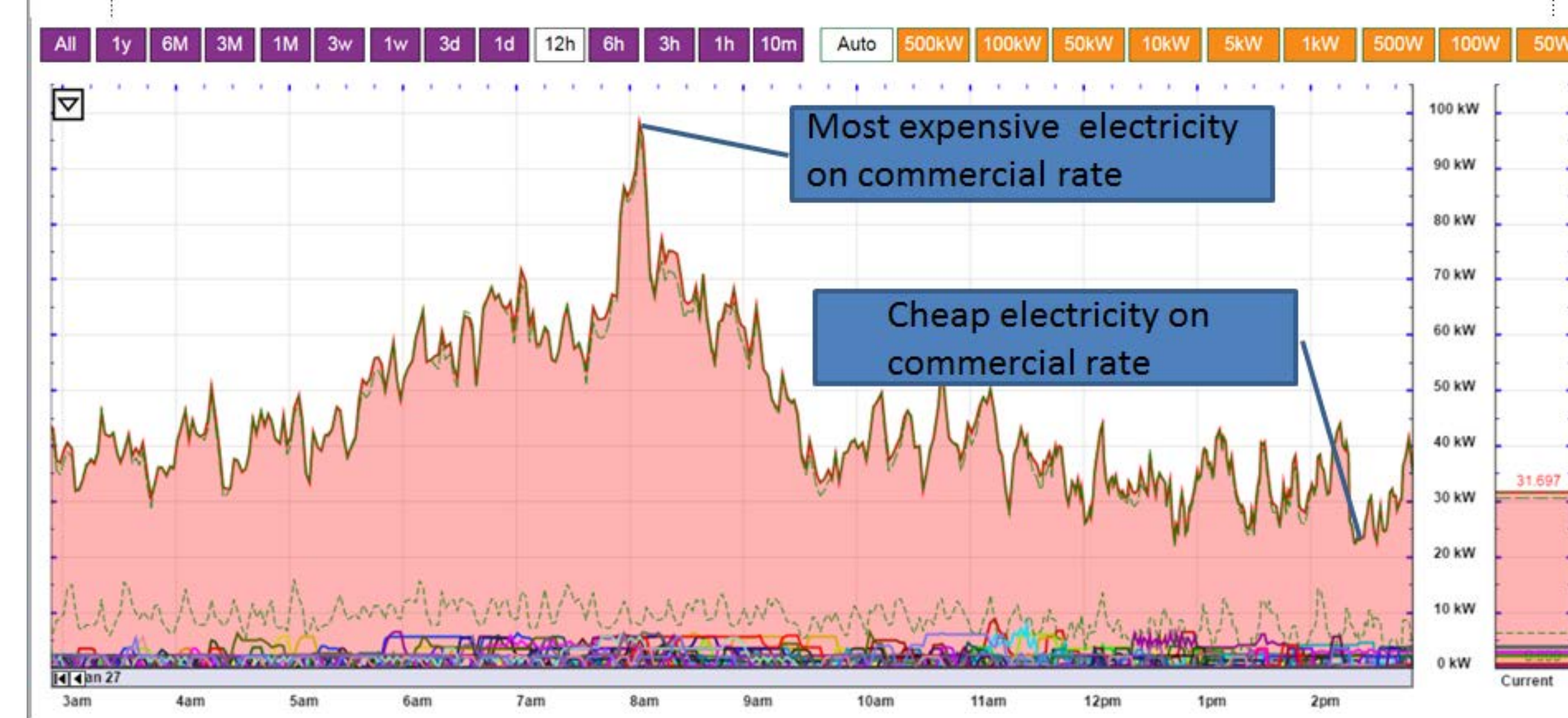


## 2018: Next Generation Modular Apartment

- Target zero energy ready status based on ESIF Prototype solutions
- Optimize design, factory prefab, technology, control, and tenant engagement to overcome split incentive, first cost, and large PV integration barriers
- Create a marketplace to grow U.S. Manufacturing of zero energy ready modular urban apartments



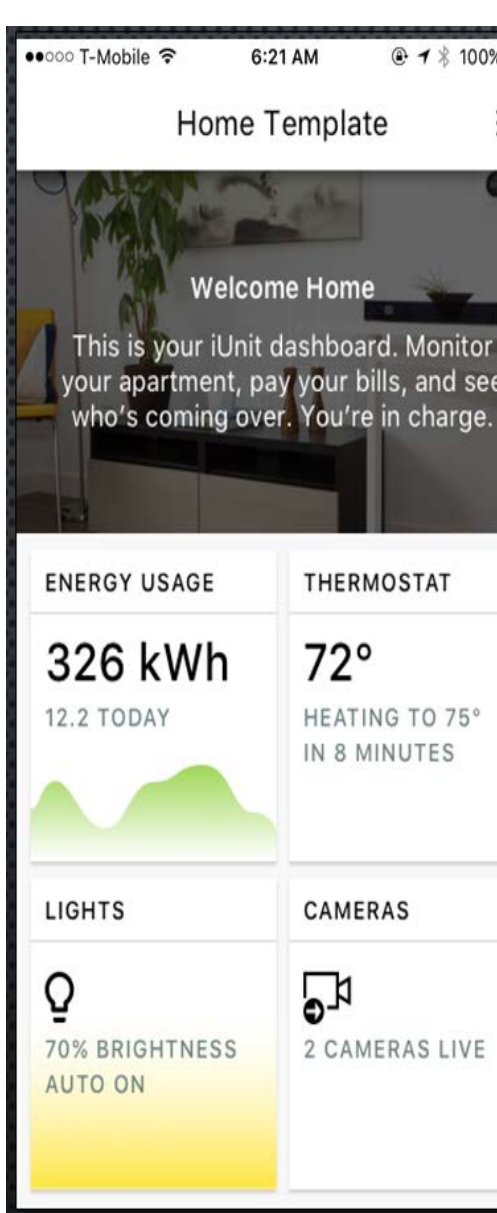
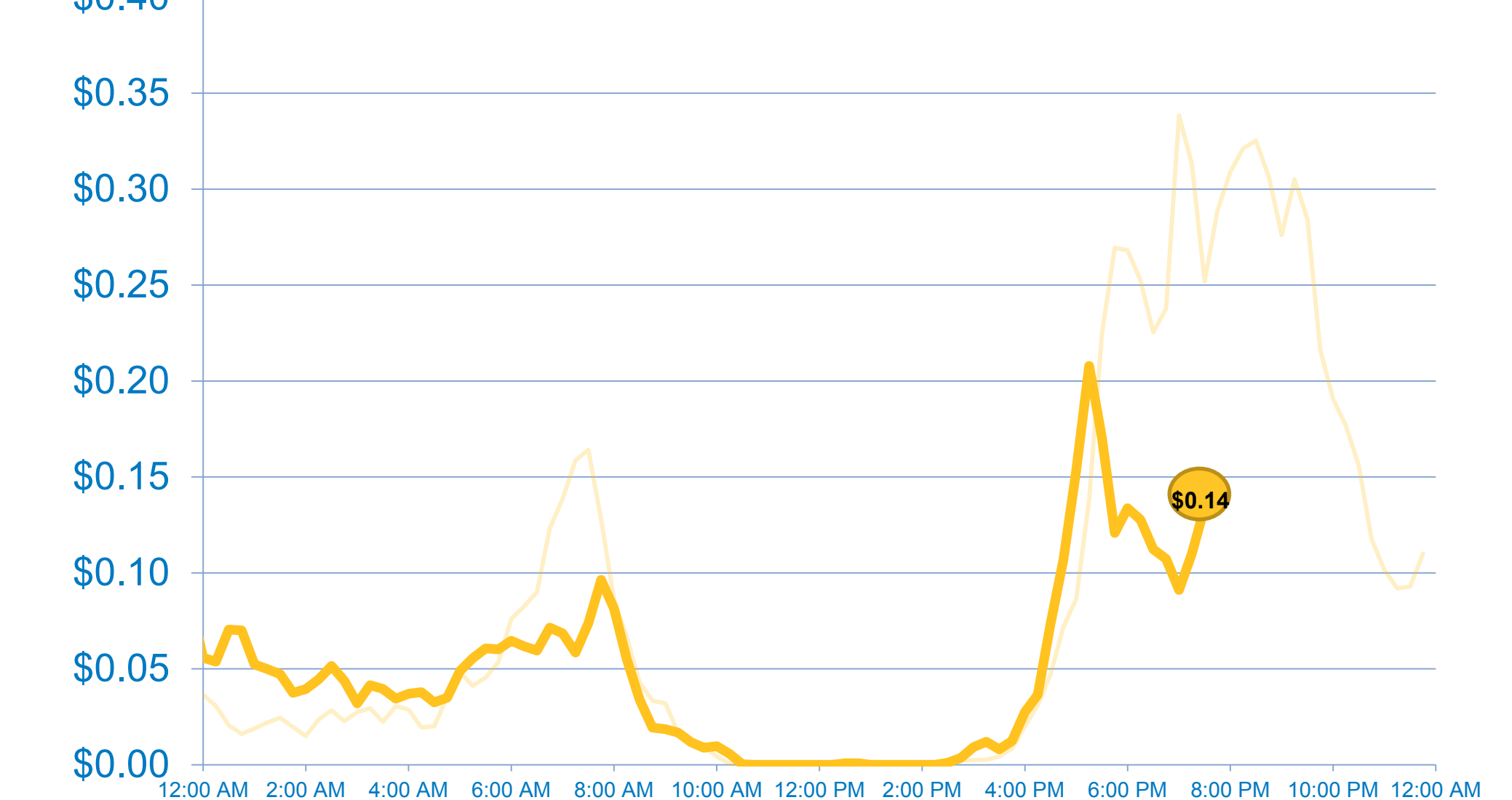
## Whole Building Load Shapes Reproduced in Load Banks In-the-Loop at ESIF



## Modular Apartment Innovations

- Hot Water**  
Assess integration of novel hot water systems to understand the value of hot water drain isolation and available wastewater temperatures.
- Renewable Energy Integration**  
Utilize factory assembly process for cost-effective installation and load-shape management.
- Building Envelope**  
Determine additional savings possible from quality-controlled air barriers and insulation systems with factory installation.
- Tenant Feedback Platform**  
Develop a software-based behavior change feedback platform to overcome split incentives barriers in Multifamily sector, enabling large PV system integration and empowering occupants to understand how to participate in making apartment load shape more grid friendly.
- HVAC**  
Develop an improved modular HVAC solution that enhances indoor air quality and maximizes heating/cooling efficiencies.

### Real Time Cost of Electricity for Each Apartment (\$/kWh)



## Apartment-in-the-Loop – Next Steps

- Develop and Run ESIF single prototype apartment efficiency and load management strategies
  - Load reduction strategies (better envelope, windows, equipment)
  - Hot water, dryer, PTHP all with heat pumps
  - Tenant engagement and feedback app behavior change
- Scale Tenant Agent Simulations to full 50+ all electric unit apartment building with large PV system
  - Cluster analysis of tenant agent archetypes
  - Use HPC and OpenStudio to simulate 50+ apartments
  - Evaluate commercial building rate implications
  - Enable large PV and centralized load shape management
    - Shape, shimmy, shift, shed
  - PV simulator tied to Battery UPS/peak demand management solution in ESIF Energy Storage Laboratory
    - Can a typical apartment building elevator (unique inrush and reactive power needs) be backed up with a battery ups?
      - Save \$50k+ for backup diesel generator AND enable larger PV and more grid friendly load shape



**"America's construction industry productivity is lower today than it was in 1968."**

The report calls for a global effort to modernize and upgrade the construction industry across seven broad areas:

- Reshape regulation and raise transparency
- Rewire the contractual framework
- Rethink design and engineering processes
- Improve procurement and supply-chain management
- Improve on-site execution
- Infuse digital technology, new materials, and advanced automation
- Reskill the workforce

"Parts of the industry could move toward a manufacturing-inspired mass-production system, in which the bulk of a construction project is built from prefabricated standardized components off-site in a factory. Adoption of this approach has been limited thus far, although it's increasing. Examples of firms that are moving in this direction suggest that a productivity boost of five to ten times is possible."

<http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

## ENERGY SYSTEMS INTEGRATION

ESI optimizes the design and performance of electrical, thermal, fuel, and water pathways at all scales.

- Energy Systems Integration Facility is NREL's largest R&D facility (182,500 ft<sup>2</sup>)
- Space for 200 NREL staff and research partners
- 15 state-of-the-art hardware laboratories
- Integrated megawatt-scale electrical, thermal and fuel infrastructure
- High performance computation and data analysis capabilities
- 2-D/3-D advanced visualization



**Integrated, mega-watt scale power hardware-in-the-loop (PHIL) capability allows researchers and manufacturers to test new energy technologies at full power in real-time simulations—safely evaluating component and system performance and reliability before going to market**