Integrating Energy Efficiency into the Permanent Modular Construction Industry

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NREL Buildings Integration Research
Team

NREL Buildings Researchers

- **Shanti Pless**
  Senior Research Engineer

- **Stacey Rothgeb**
  Senior Research Engineer

- **Ankur Podder**
  Research Engineer

- **Noah Klammer**
  Graduate Researcher

Industry Advisory Group

- Momentum Innovation Group
- School of Civil and Construction Engineering, Oregon State University
- WSU ModLab
- Modular Building Institute
- Industry Trade Association, World of Modular

High-performance building systems integration
Open Studio tool development and life-cycle cost optimization
Apartment-in-the-loop research platform
Factory Partners with Pilot Projects

Factory_OS – Vallejo, CA

Volumetric Building Companies – Hamlet, NC

Skender – Chicago, IL

FullStack Modular – Brooklyn, NY
Zero Energy Mixed-Use and Multifamily: 2019 Site Built Examples

Boulder Commons

Photos from Boulder Commons

UC Davis Student Housing at Net Zero

Photos from UC Davis West Village
Zero Energy Mixed-Use and Multifamily: Site Built Energy Strategies

- Near Passive House levels of insulation
  - Enhanced airtightness
- Triple-pane windows
  - Electrochromic, automated shades
- 100% LEDs
- Electric heating and hot water
  - Heat pump hot water heating
  - Variable refrigerant flow, air source, ground source heat pumps
- High-efficiency appliances
- Technology, tenant monitoring, and control integration
  - Smart home technology
- Unit-level facade and rooftop photovoltaics (PV)
  - Battery storage and grid-coordinated controls
Barriers in the Building Energy Efficiency World

Site-Built Zero Energy Buildings:
- High first costs
- Too complex
- Skilled labor difficult to find
  - As well as experienced developers and designers
- Suffer from poor quality of installation
- New risk
  - We need to prove it can be done all the time
- Lack of owner interest

Sound familiar?

Not just building energy efficiency barriers...
Permanent Modular Off-Site Construction

- 20%–40% faster to build*
- 5%–95% construction off-site in a factory*
  - Volumetric modular, wall panels, etc.
- 3% of new construction in 2017*
  - Multifamily and hotels
- Higher quality
- Can be cheaper to build...
- Any program that can be modularized
- New investment from outside construction industry

But does it result in more efficient buildings? Perhaps...

*Modular Advantage by Modular Building Institute (https://www.modular.org)
Why Energy Efficiency and Off-Site Construction?

Energy codes are quickly progressing

• Are you ready for zero energy?
• Now is the time to figure out how benefits of off-site construction can be used to meet the upcoming energy codes that are more stringent
• Can the off-site approach be used to more cost-effectively meet upcoming codes to address affordability and energy trends?

Many projects are in cities with 100% renewable commitments

• Can lead to better alignment with city approval decision makers
Why Energy Efficiency and Why Off-Site?

Saving money each month is more important in affordable housing
  • Up to 50% energy cost savings now possible

Energy efficiency savings can cost-effectively be achieved if integrated well into off-site manufacturing processes
  • Energy efficiency savings can easily be achieved with attention to quality

Nonenergy reasons for off-site
  • Can enhance health, indoor air quality, safety, durability, resiliency, acoustics, and climate
“America’s construction industry productivity is lower today than it was in 1968.”

“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.”

The Need for Affordable Housing

• The United States will need to build an average of 324,000 new apartments each year to keep up with demand
• At least 4.6 million new apartments by 2030
• 20.4 million existing apartments today
  o As many as 11.7 million will need to be renovated by 2030

63% of apartments in 2030 will be new or renovated.

Image from the National Apartment Association and the National Multifamily House Council
“Off-site construction of housing, which leverages the efficiencies of factory production to achieve significant cost savings, represents a much needed solution to this problem. It has the potential to revolutionize the way homes and apartments are built.”

“Inefficiencies in traditional construction have hampered productivity and driven costs up for decades, resulting in increasingly costly development. Today, in many regions in the United States, the production of housing—especially infill multifamily housing—has become so costly to produce it demands rents or sale prices that are unaffordable for most people.”

Off-site construction can reduce project construction time by between 40 and 50 percent, because several aspects of the construction process can be completed simultaneously, rather than sequentially as is required in traditional construction.

Fewer months on-site also reduces expenses such as general contractor fees, utilities, security, and other related facility costs. A shorter time frame also has the benefit of minimizing length of impact on neighbors.”
## Example apartment project construction duration, traditional vs offsite 3D volumetric, months

<table>
<thead>
<tr>
<th>Months</th>
<th>6</th>
<th>12</th>
<th>18</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Traditional</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning and design</td>
<td></td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foundations</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Onsite construction</td>
<td></td>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Construction over-run</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

**3D volumetric**

<table>
<thead>
<tr>
<th>Months</th>
<th>6</th>
<th>12</th>
<th>18</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning and design</td>
<td>5–7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foundations</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offsite manufacture</td>
<td>Enhanced productivity in factory allows fast module build</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onsite installation</td>
<td>Fast assembly because no MEP and finishing personnel required</td>
<td>3–6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Redesign is frequent in traditional construction, but very rare in offsite. 20–50% faster.

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Leverage the emerging factory construction benefits of higher quality, faster construction timeline, improved productivity, increased technology integration, and labor cost savings to enable cost-effective, energy efficiency, integrated grid interactive controls, and renewables.

Research Question: How can optimal integration of energy efficiency strategies and control systems be achieved through advanced manufacturing techniques and technologies with little or no additional cost?

Partner with leading factories and showcase projects to achieve optimal integration of energy systems within the emerging advanced manufacturing industry for buildings.
NREL and iUnit: Leading the Design for Net Zero Multifamily Construction

NREL is collaborating with Denver developer iUNIT, using the Energy Systems Integration Facility's apartment-in-the-loop research capabilities and energy modeling tools to lead the design, demonstration, and integration of net zero, grid-friendly, and technology-integrated multifamily construction.

Story at: https://www.nrel.gov/esif/partnerships-iunit.html
iUnit Modular Apartment Development History

www.iunit.co

V1: 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

Photo by Dennis Schroeder, NREL
NREL’s Modular Test Unit
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.

**Building Envelope**
Determine additional savings possible from quality-controlled air barriers and insulation systems with factory installation.

**HVAC**
Develop an improved modular HVAC solution that enhances indoor air quality and maximizes heating/cooling efficiencies.

**Renewable Energy Integration**
Utilize factory assembly process for cost-effective installation and load-shape management.

**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.
## iUnit Improvements with Off-Site

<table>
<thead>
<tr>
<th></th>
<th>$/ft²/yr</th>
<th>$/yr Electricity Use</th>
<th>kWh/yr</th>
<th>Site EUI</th>
<th>Source EUI</th>
<th>Source Energy Savings</th>
<th>EnergyStar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Existing All-Electric Multifamily Apartment Building (Based on ES 50)</td>
<td>$2.05</td>
<td>$48,027</td>
<td>320,182</td>
<td>47</td>
<td>131</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Typical New All-Electric Multifamily Apartment Building (Based on ES 75)</td>
<td>$1.73</td>
<td>$40,402</td>
<td>269,348</td>
<td>39</td>
<td>110</td>
<td>16%</td>
<td>75</td>
</tr>
<tr>
<td>Eliot Flats 2017 with 14 kW PV (2017 Measured)</td>
<td>$1.43</td>
<td>$33,423</td>
<td>222,824</td>
<td>33</td>
<td>91</td>
<td>30%</td>
<td>91</td>
</tr>
<tr>
<td>Eliot w/ NREL prototype 2017 with 14 kW PV (Measured Prototype)</td>
<td>$1.11</td>
<td>$26,039</td>
<td>173,599</td>
<td>25</td>
<td>71</td>
<td>46%</td>
<td>99</td>
</tr>
<tr>
<td>Eliot w/ enhanced NREL prototype 2018 with 14 kW PV, demand management, and commercial rate (Modeled Goal)</td>
<td>$0.75</td>
<td>$17,560</td>
<td>151,000</td>
<td>22</td>
<td>61</td>
<td>53%</td>
<td>100</td>
</tr>
</tbody>
</table>
A Process for Embedding Energy Efficiency Strategies into Advanced Manufacturing

**Benchmark**
- Code → High Performance
- Pilot technologies
- Baseline dataset from factory partners

**Recommendations and Factory Pilot**
Develop initial set of energy solutions for factory partners to consider

**Discrete Event Model**
- Modeling
- Simulation
- Baselining: code to high performance pilot technologies

**Integration: Energy Savings/ Cost Effective**
Document cost savings pathways for replication
Factory Information Model (FIM) with Integrated Building Energy Model (BEM) for Advanced Manufacturing Assessment Framework

FIM Outputs:
- Material Costs
- Equipment
- Process Improvements
- Quality Controls
- Construction Sequence Steps
- Change in Timing and Installation Costs
- Visualizations for process improvement training and consideration

BEM Outputs:
- Energy Savings of Integrated EE and Controls Commissioning
- Energy Cost Savings

Energy Efficiency and Factory Installation Recommendations:
- Envelope and air sealing
- Smart Apartment Tech
- Integrated HVAC and HRVs

Existing BIM to BEM Translators
OpenStudio®

3D Building Info Model (BIM)
2D Discrete Event Simulation
3D Process Visualization

Factory Logistics Data Collection
Assembly layout, process mapping, material flows and costs, module design, etc.
Example of Permanent Modular Construction Factory

Station 1A: Floor Prep, Floor Build
Station 2, 2A: Plumbing Set
Station 3: Flooring
Station 6: Wall Set
Station 9: Wall Push Up
Station 10: Ceiling Set
Station 21: Truck Set
Factory Process Modeling Approach

Data-Driven Discrete Event Simulation for Digital Twin
Captures spatiotemporal interactions between human labor, material, equipment, and available space on the factory floor

• Identifies bottlenecks

• Identifies opportunities to integrate energy efficiency strategies on the factory line

• **Phase 1: Sensors-Led Data Acquisition from Factory**
• **Phase 2: Machine Learning-Based Optimization**
• **Phase 3: Data-Driven Discrete Event Simulation on the 3D Digital Twin**

Technical Partner: Dr. Joseph Louis, Oregon State University (OSU)
A Process for Embedding Energy Efficiency Strategies into Advanced Manufacturing

**STRATEGIES**
- ENCLOSURE
- HVAC
- SMART APARTMENT

**ADVISORY GROUP AND SUBGROUPS**
- 50+ interested industry participants
  - Provide guidance and technical support
  - Help develop standards document

**PARTNERS**
- Factory OS
- FullStack Modular
- Volumetric Building Companies
- Skender
How can optimal integration of energy efficiency strategies and control systems be achieved through advanced manufacturing techniques and technologies with little or no additional cost?

### Energy-Efficient Strategies Currently in Progress with Factory Partners

<table>
<thead>
<tr>
<th>Digital Twins</th>
<th>Envelope</th>
<th>Controls</th>
<th>Equipment</th>
<th>Renewables</th>
</tr>
</thead>
</table>
| Factory Information Model + Building Energy Modeling | • Maximize life cycle cost savings of insulation systems that include factory installation cost profile  
• Air barrier improvements on the factory line | Occupant Engagement Platform | • All-electric DHW  
• Volumetric modular scale HVAC to maximize equipment off-site installation  
• Appliances | “Factory installed solar reduces the cost of residential solar by 40%.”  
[www.solarhomefactory.com](http://www.solarhomefactory.com) |
Energy Efficiency and DER in Off-Site: Possible Pathways for Energy Efficiency Integration

Vision for integration of energy modeling into off-site design and fabrication process

DOE/NREL Energy Modeling Capabilities

• OpenStudio/BeOpt™ and EnergyPlus®
  o Develop energy modeling tools used in industry

• Core capabilities in modeling of high-performance multifamily
  o Zero Energy Design Guide for Multifamily
    ▪ Zero Energy ready multifamily design standards in OpenStudio
  o BeOpt Multifamily
  o Detailed occupant driven end use characterization
  o Sector-wide modeling studies to assess MF stock improvements
    ▪ 100% renewables for LA city-wide study

Building Energy Modeling integration into the digital design-factory process and software tools

• OpenStudio energy modeling platform integration
• Off-line life cycle cost analysis for standardized designs
• Streamline energy design modeling of individual projects
  o Zero energy design
  o Code compliance, LEED, etc.
Energy Efficiency and DER in Off-Site: Possible Pathways for Energy Efficiency Integration

Envelope

• Maximize life cycle cost savings of insulation systems that include factory installation cost profile
  o More insulation at a better quality possible with lower installation costs
  o Additional wall/floor/roof cavities available due to structural requirements of volumetric modular

• Utilize inherent envelope air barrier quality control opportunities to ensure higher airtightness
  o Low infiltration levels can be reached more cost-effectively and inherently
  o Common interface issues around windows can be detailed and installed with higher quality
  o Manufacturing line air barrier quality control testing
Air Barrier Improvements on the Factory Line?

• ACH50 7–8 typical
• ACH50 3–4 inherent in off-site modular
  o Baseline tested at VBC
• ACH50 1–3 is the goal
• What factory line improvements can we develop to reach the air barrier goals?
Energy Efficiency and DER in Off-Site: Smart Apartment in a Box

EE Controls and Occupant Engagement Platform

• Explore viable integration of EE and GEB controls into emerging smart apartment technology solutions
• Grid-integrated HVAC and hot water controls that optimize to utility price signals and renewables
• Enable single utility meter with software submetering and tenant feedback with monthly budgets
• Implement submetered module with hourly real-time pricing, set monthly allocation, and enable real-time tracking against monthly utility bill budgets
  o $25/month included in rent, power bill if go over monthly cap
  o Rank your use vs others in the building
• Develop factory quality control measures to ensure EE controls and data platform work as intended from factory

Photo by Dennis Schroeder, NREL
Example of Modular Apartment Prototype

“We have already uncovered several manufacturing efficiencies through the creation of this prototype, including the ability to install smart apartment tech at a fraction of the cost it would normally take to install in an already-existing unit.”

Energy Efficiency and DER in Off-Site: Possible Pathways for Energy Efficiency Integration

All-Electric DHW

- Heat recovery options from wastewater, grid responsive control integration
- Module-scale heat pump hot water heater integrated with HVAC
- Grid controllable water heater
  - Delay, setpoint, leak alarms, real time price triggers

Photo by Dennis Schroeder, NREL
Energy Efficiency and DER in Off-Site: Possible Pathways for Energy Efficiency Integration

Volumetric modular-scale HVAC to maximize equipment off-site installation

- Identify modular scale HVAC system with efficiency of larger centralized systems
- Integrated exhaust and ventilation heat recovery with dehumidification/heating/cooling solutions
- Streamline the module to module HVAC system interconnections
Energy Efficiency and DER in Off-Site: Possible Pathways for Energy Efficiency Integration

Shared Development Integrated Platform for HVAC Pod

Proposed Components

- Heat Recovery Ventilator (HRV)
- Heat Pump Water Heater
- Outdoor Unit with Minisplit
- Heat Pump Ventless Dryer
- Washer
- Integrated Control Metering and Fault Detection
- Supply Ducts
- Bathroom Exhaust Ducted In
- Preheater
- Battery (LFP)
- Phase Change Materials
Appliances

- Ventless dryers to eliminate exhaust vent maintenance and separate envelope penetration
- Induction cooking
Energy Efficiency and DER in Off-Site: Possible Pathways for Energy Efficiency Integration

Renewables and Storage
• Single meter to enable large-scale PV, with unit submetering
• Modular electrical room(s) with battery UPS and demand management
• Facade rainscreen and rooftop PV installed off-site
• In-unit battery storage for demand management and backup UPS
• Document cost-savings pathways for replication

“Factory installed solar reduces the cost of residential solar by 40%.”
www.solarhomefactory.com

Ryan Wallace
CEO, Solar Home Factory
Factory Built Multifamily: Factory_OS—Vallejo, CA

https://www.youtube.com/watch?v=Y21XdogUbRU
Thank You

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