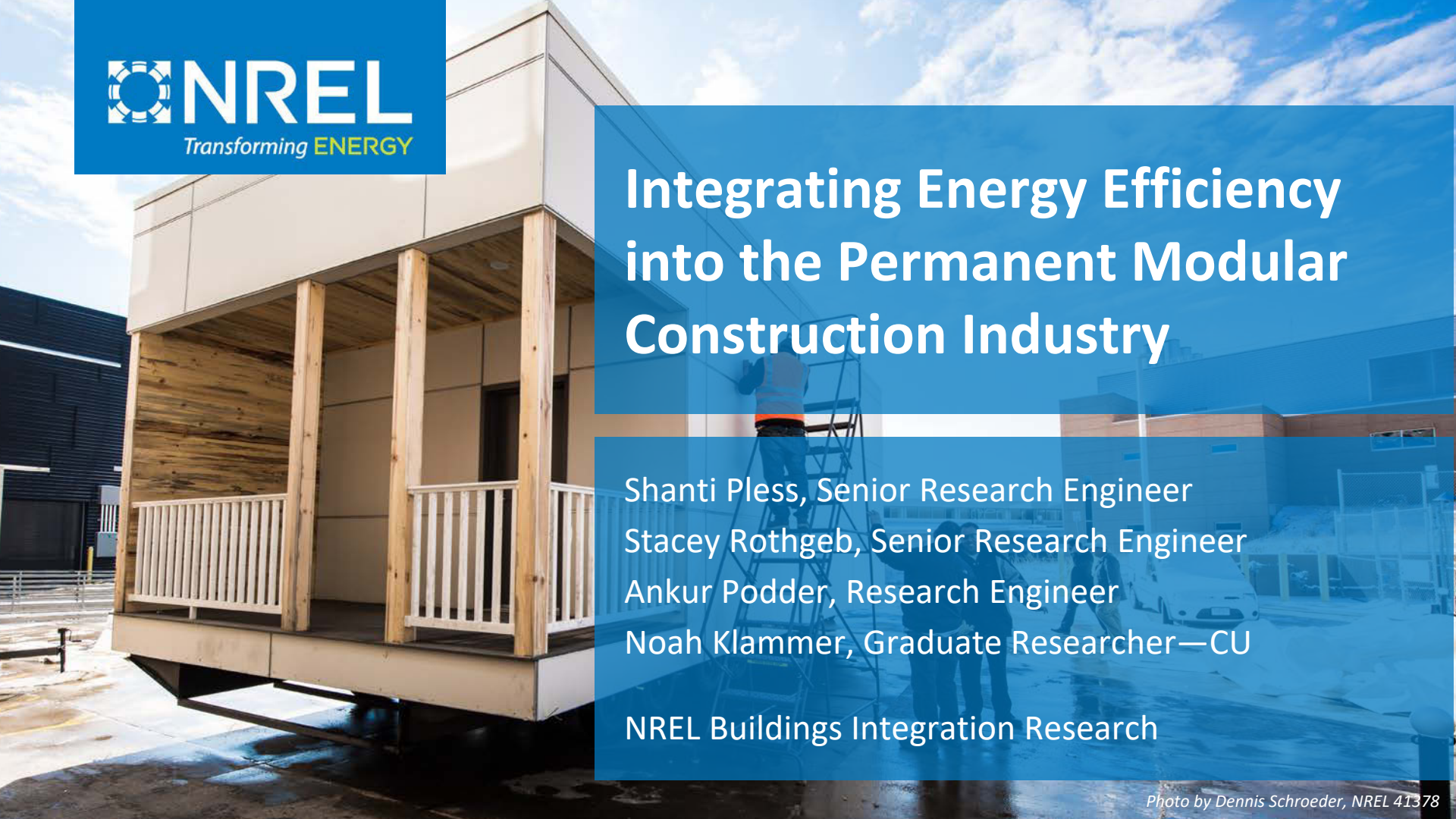


Integrating Energy Efficiency into the Permanent Modular Construction Industry

Shanti Pless, Senior Research Engineer
Stacey Rothgeb, Senior Research Engineer
Ankur Podder, Research Engineer
Noah Klammer, Graduate Researcher—CU

NREL Buildings Integration Research

Photo by Dennis Schroeder, NREL 41378

Team

NREL Buildings Researchers

Shanti Pless
Senior Research Engineer

Stacey Rothgeb
Senior Research Engineer

Ankur Podder
Research Engineer

Noah Klammer
Graduate Researcher

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

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

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

Images from Revive Properties

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?

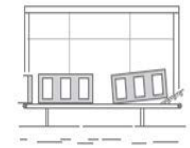
Not just building energy efficiency barriers…

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)


Assembled in a factory


Transported to site


Assembled


Connect to grid

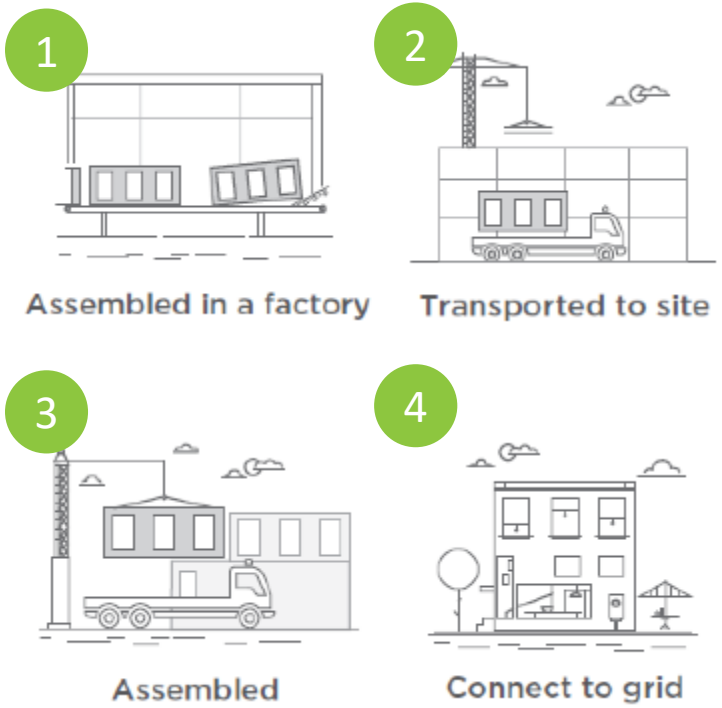
Why Energy Efficiency and Off-Site Construction?

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?

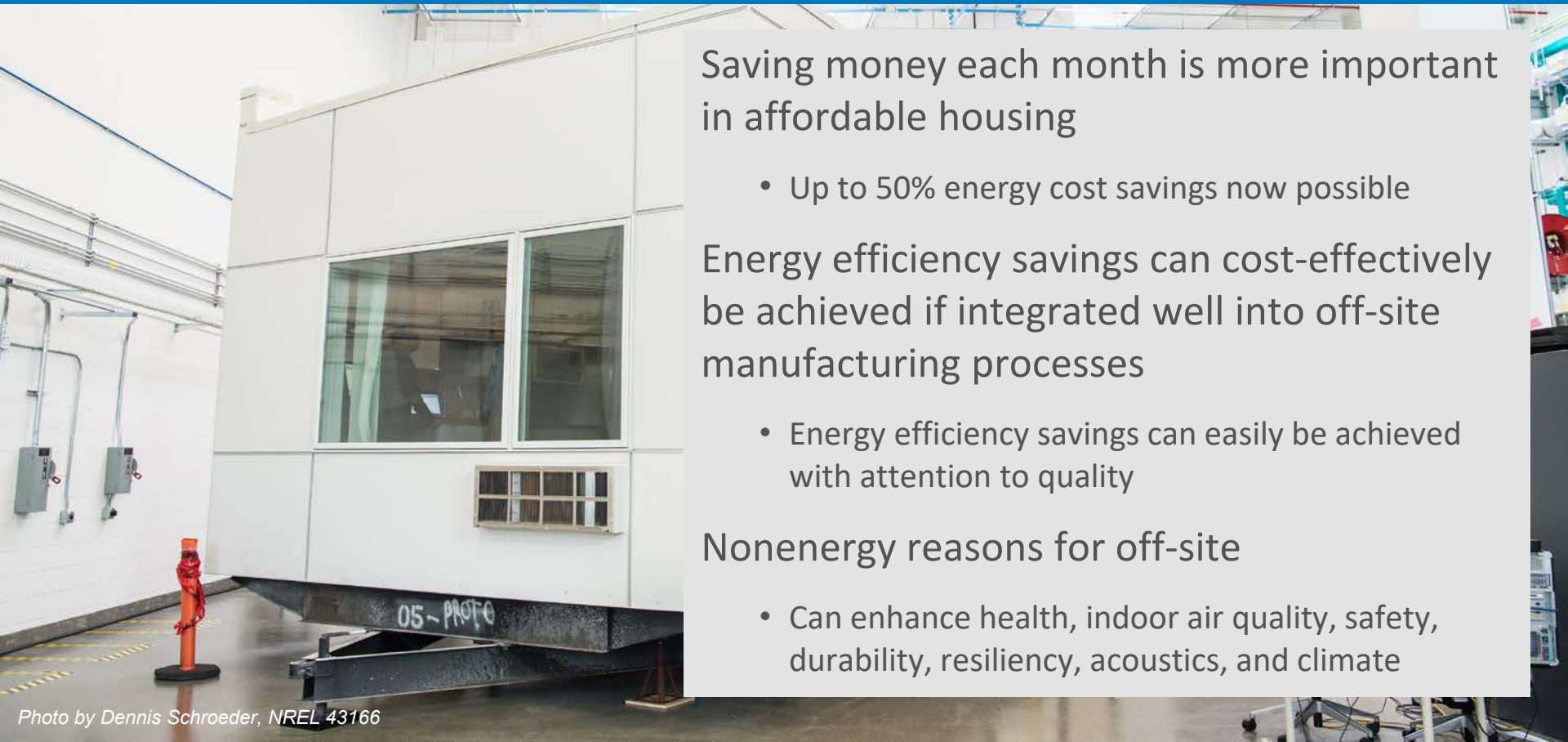


Photo by Dennis Schroeder, NREL 43166

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.”

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

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
  - 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

TERNER CENTER FOR HOUSING INNOVATION
UC BERKELEY

SEARCH

CAREERS

CONTACT US

BUILDING AFFORDABILITY BY BUILDING AFFORDABLY: THE CASE FOR OFF-SITE MULTIFAMILY CONSTRUCTION

POSTED ON MARCH 07, 2017 BY CAROL GALANTE AND SARA DRAPER-ZIVETZ

...emain releva... ...nanging dem... ...stry is no ex... ...revolutions ... ...rapidly char... ...nces, and a... ...lier than eve... ...will the hou... ...n McKinsey &... ...er said, over... ...nstruction 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. While the cost of construction is not the *only* reason housing prices continue to increase, they are certainly a major factor.

"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."

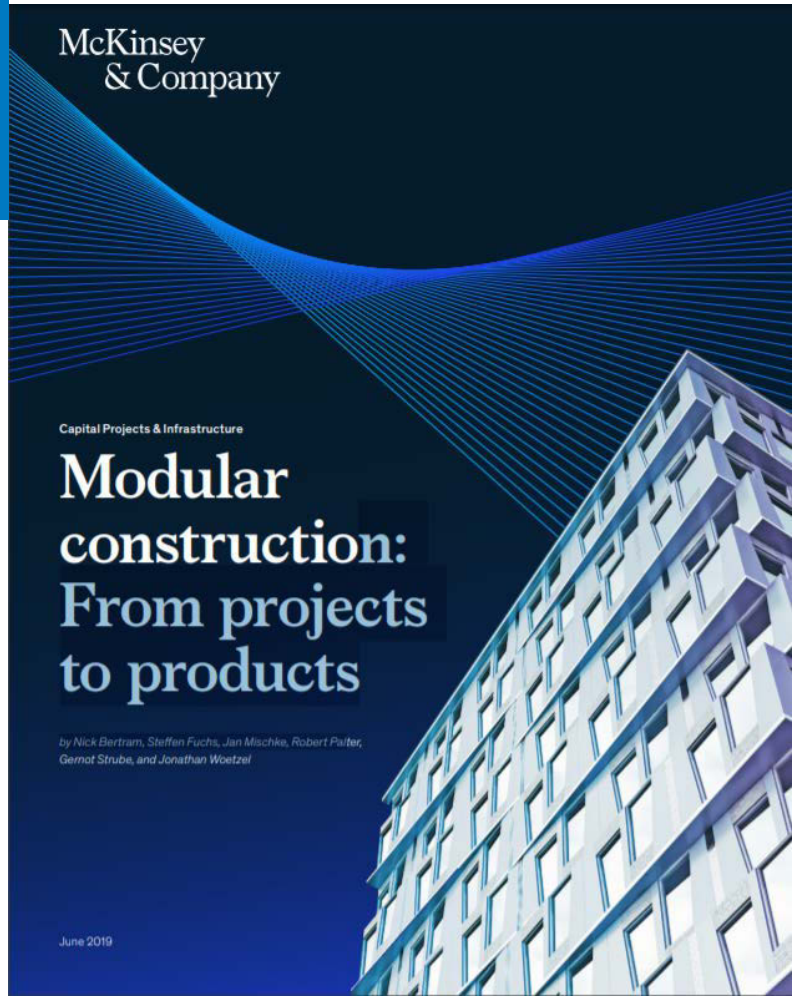
http://ternercenter.berkeley.edu/uploads/offsite_construction.pdf; also reported in http://modular.org/documents/document_publication/mckinsey-report-2019.pdf

Off-Site Will Save Time and Money

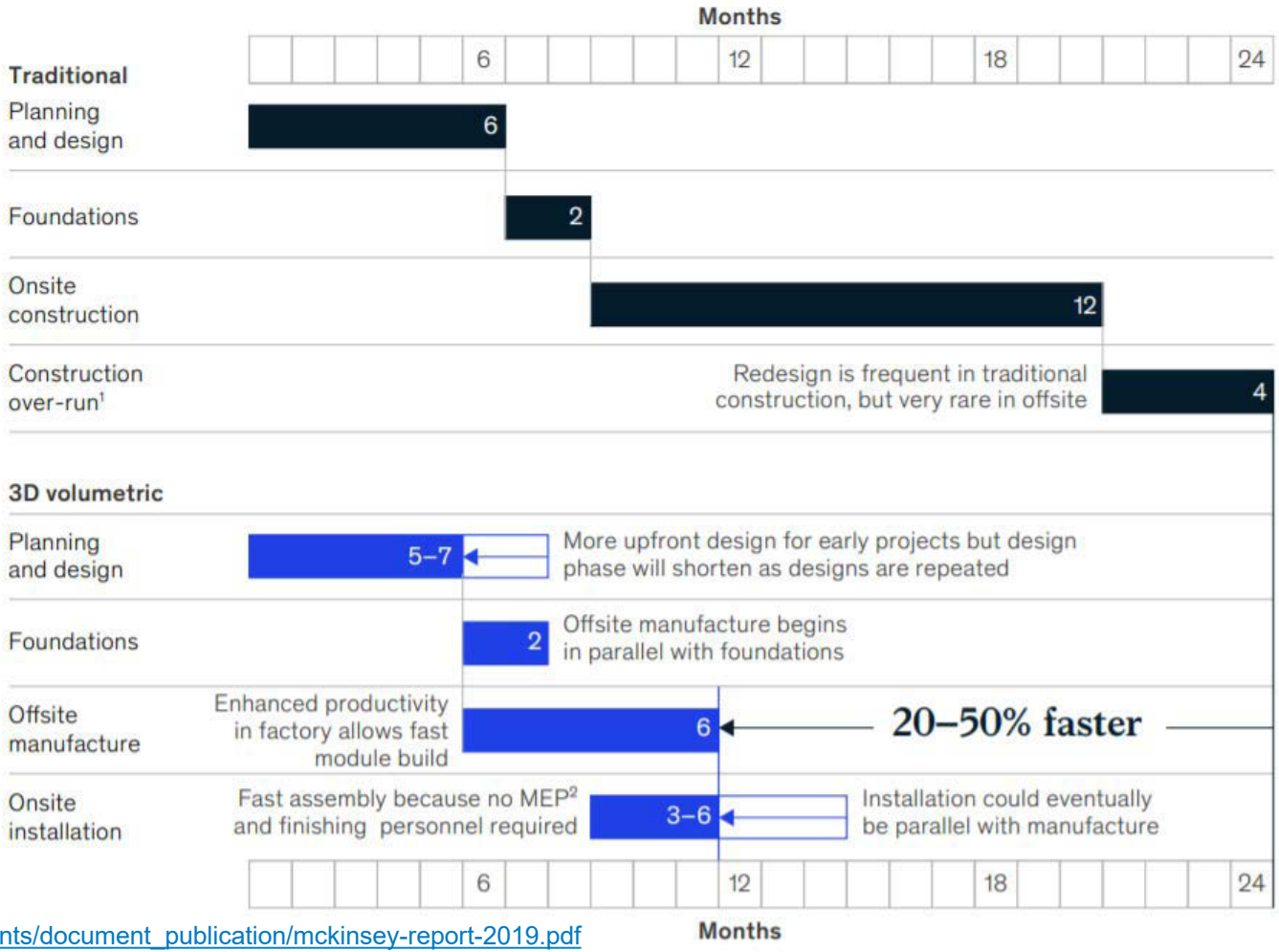
"**Off-site construction can reduce project construction time by between 40 and 50 percent**, because several aspects of the construction process can be completed simultaneously, rather than sequentially as is required in traditional construction.

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."

http://modular.org/documents/document_publication/mckinsey-report-2019.pdf



Example apartment project construction duration, traditional vs offsite 3D volumetric, months



http://modular.org/documents/document_publication/mckinsey-report-2019.pdf

2019–2021 Energy Efficiency in Off-Site Construction Research

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.

iUnit Brings 380-Square-Foot Modular Apartment to the ESIF to Evaluate Advanced, Multifamily Construction

Roughly 38 million people in the United States live in buildings that contain five or more units, totaling almost 18.5 million households. Increasing energy efficiency in America's multifamily apartment buildings, however,

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


iUnit Denver Delivery


Photo by Dennis Schroeder, NREL

Eliot Flats, Denver

NREL's Modular Test Unit

Photos by Dennis Schroeder, NREL

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

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

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

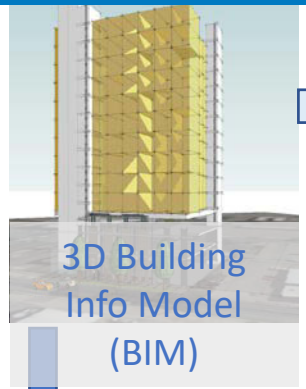
- Modeling
- Simulation
- Baselining: code to high performance pilot technologies

=

Integration: Energy Savings/ Cost Effective

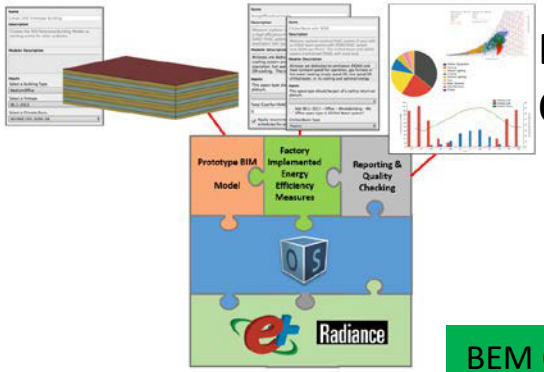
Document cost savings pathways for replication

Factory Information Model (FIM) with Integrated Building Energy Model (BEM) for Advanced Manufacturing Assessment Framework



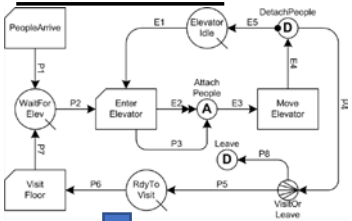
3D Building Info Model (BIM)

Existing BIM to BEM Translators



Existing BEM OpenStudio®

2D Discrete Event Simulation



Factory Logistics Data Collection

Assembly layout, process mapping, material flows and costs, module design, etc.

3D Process Visualization

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

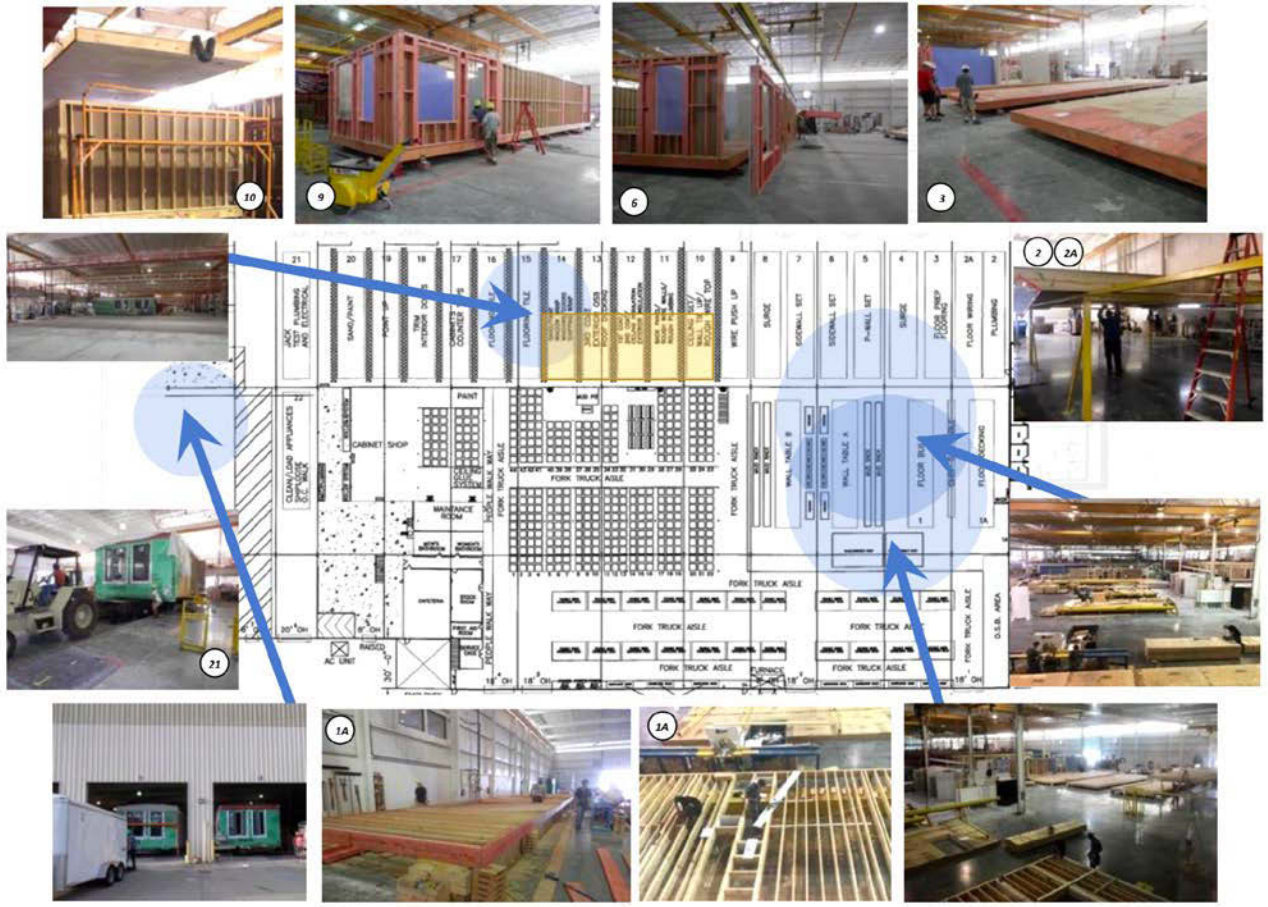
BEM Outputs:

- 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

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 floor plan of:
VOLUMETRIC BUILDING COMPANIES

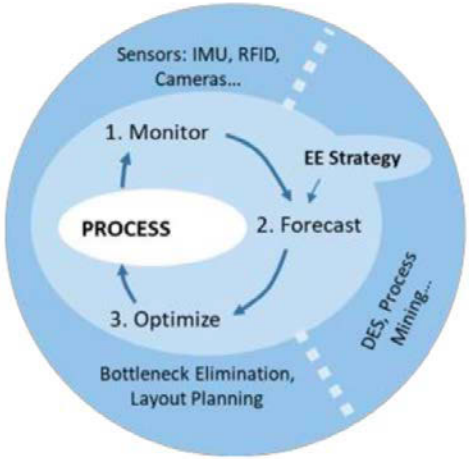
Factory Process Modeling Approach

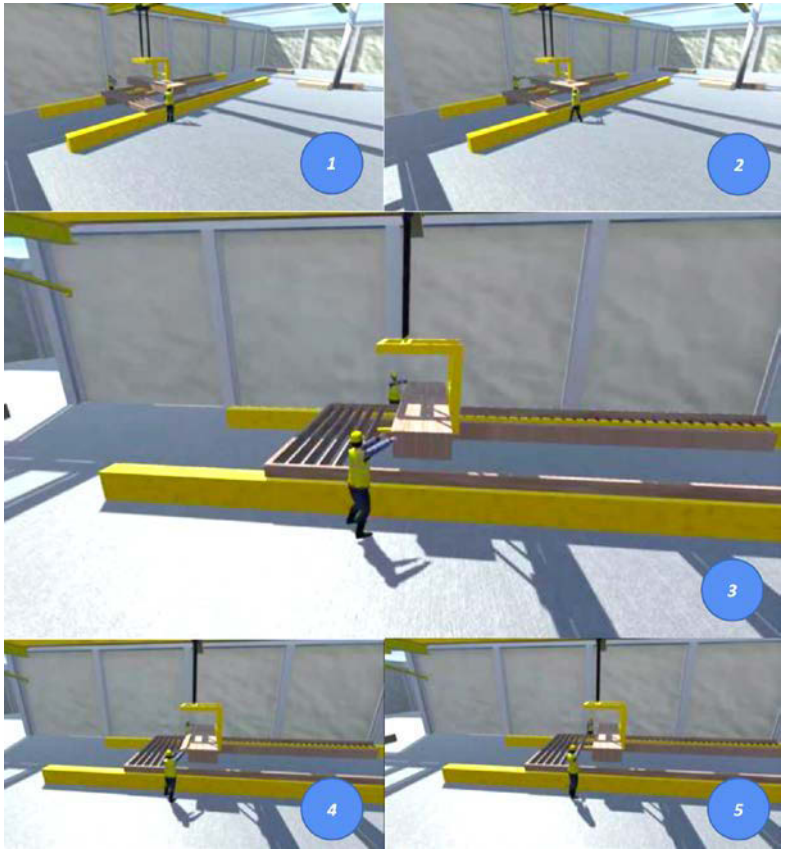
Data-Driven Discrete Event Simulation for Digital Twin

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

- Aerosol airsealing
- Advanced framing

HVAC

- ERV
- Modular scale HPS
- Package systems integration

SMART APARTMENT

- Integrated controls
- Hot water
- Renewables
- All electric

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

FY 19 | FY 20 | FY 21 | FY 22 | FY 23

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

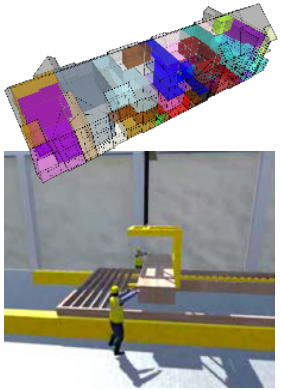
NREL
Transforming ENERGY

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

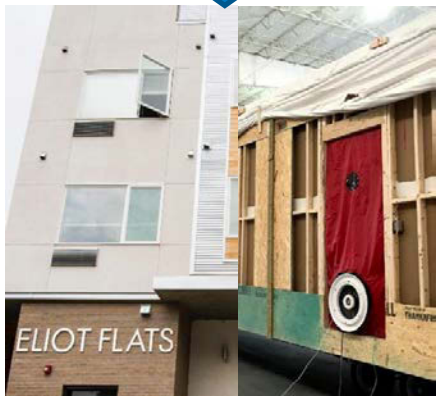
Digital Twins

Factory Information Model + Building Energy Modeling



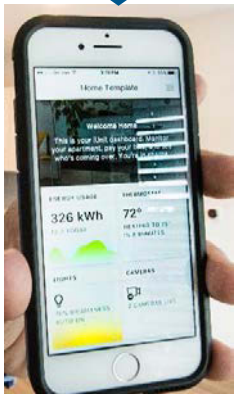
Envelope

- Maximize life cycle cost savings of insulation systems that include factory installation cost profile
- Air barrier improvements on the factory line



Controls

Occupant Engagement Platform



Equipment

- All-electric DHW
- Volumetric modular scale HVAC to maximize equipment off-site installation
- Appliances

Renewables

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

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

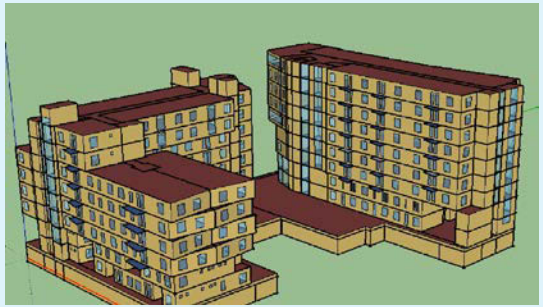
Vision for integration of energy modeling into off-site design and fabrication process

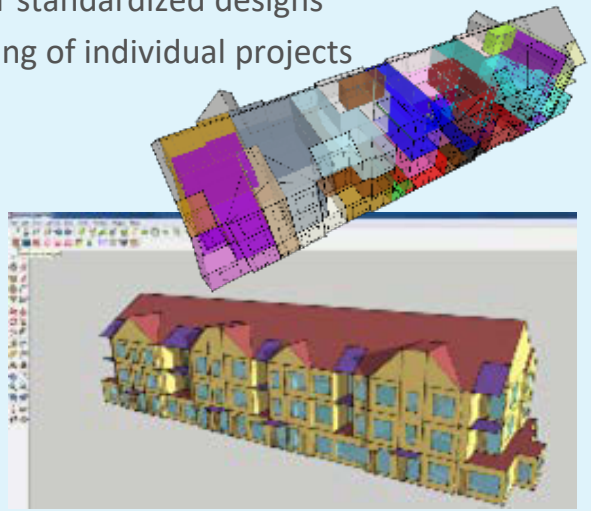
DOE/NREL Energy Modeling Capabilities

- OpenStudio/BeOpt™ and EnergyPlus®
  - Develop energy modeling tools used in industry
- Core capabilities in modeling of high-performance multifamily
  - Zero Energy Design Guide for Multifamily
    - Zero Energy ready multifamily design standards in OpenStudio
  - BeOpt Multifamily
  - Detailed occupant driven end use characterization
  - 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
  - Zero energy design
  - 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
  - More insulation at a better quality possible with lower installation costs
  - 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
  - Low infiltration levels can be reached more cost-effectively and inherently
  - Common interface issues around windows can be detailed and installed with higher quality
  - Manufacturing line air barrier quality control testing

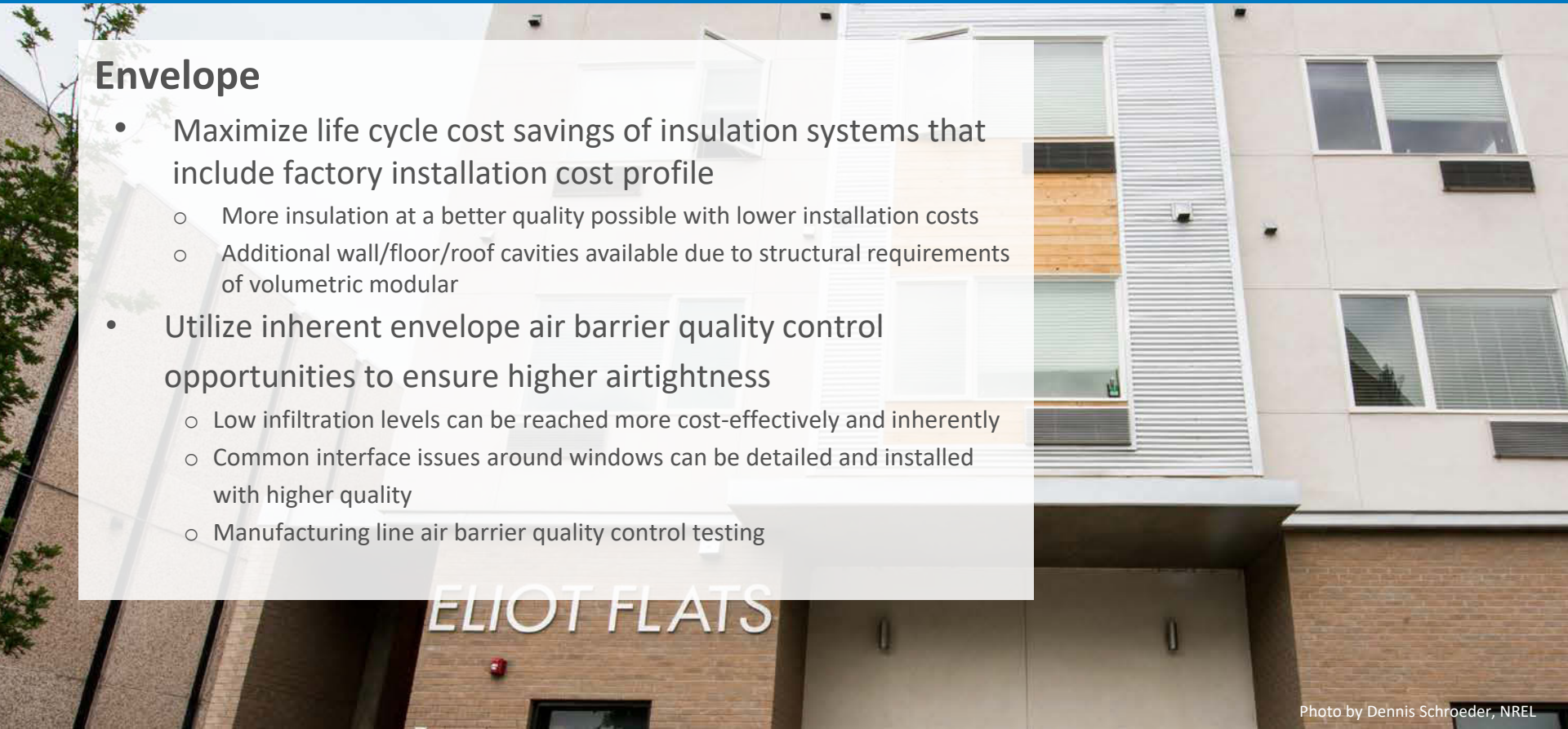


Photo by Dennis Schroeder, NREL

Air Barrier Improvements on the Factory Line?

- ACH50 7–8 typical
- ACH50 3–4 inherent in off-site modular
    - 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
  - $25/month included in rent, power bill if go over monthly cap
  - 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

Skender

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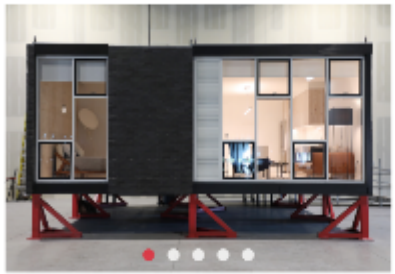
News & Media

Skender Celebrates Unveiling of Modular Smart Apartment Prototype

November 27, 2018



CHICAGO (Nov. 27, 2018) – Smart phones roll off the factory assembly line—and now, smart apartments. Skender's vision for a modular building process has reached a milestone: an actual smart apartment module prototype is complete and on display, featuring Google Home technology systems throughout its structure. The prototype is an early version of the apartment units that will be built in Skender's factory for a building in Chicago's West Loop early next year.

Yesterday, Skender unveiled its smart apartment prototype in Skender's advanced manufacturing facility on the southwest side of Chicago. The prototype demonstrates how modular design and construction has the potential to disrupt the building process making the design, manufacture and construction of buildings safer, faster and more affordable, as well as more technology and environmentally friendly.

The prototype offers a way to leverage a technology-based solution to the affordable housing crisis, and more broadly, to keep construction costs manageable and significantly reduce schedules for market rate

Share

"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."

https://www.skender.com/news-media-item/skender-celebrates-unveiling-of-modular-smart-apartment-prototype/

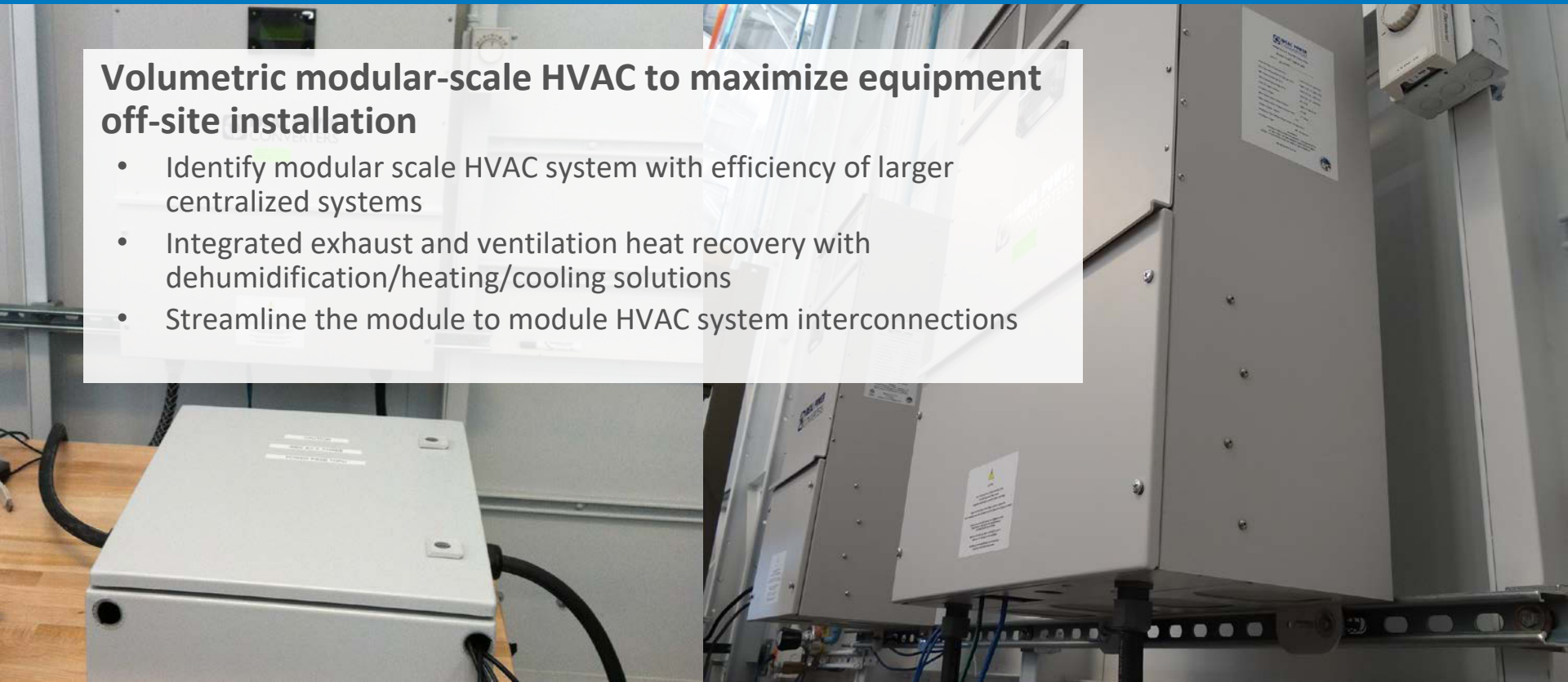
Energy Efficiency and DER in Off-Site: Possible Pathways for Energy Efficiency Integration

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

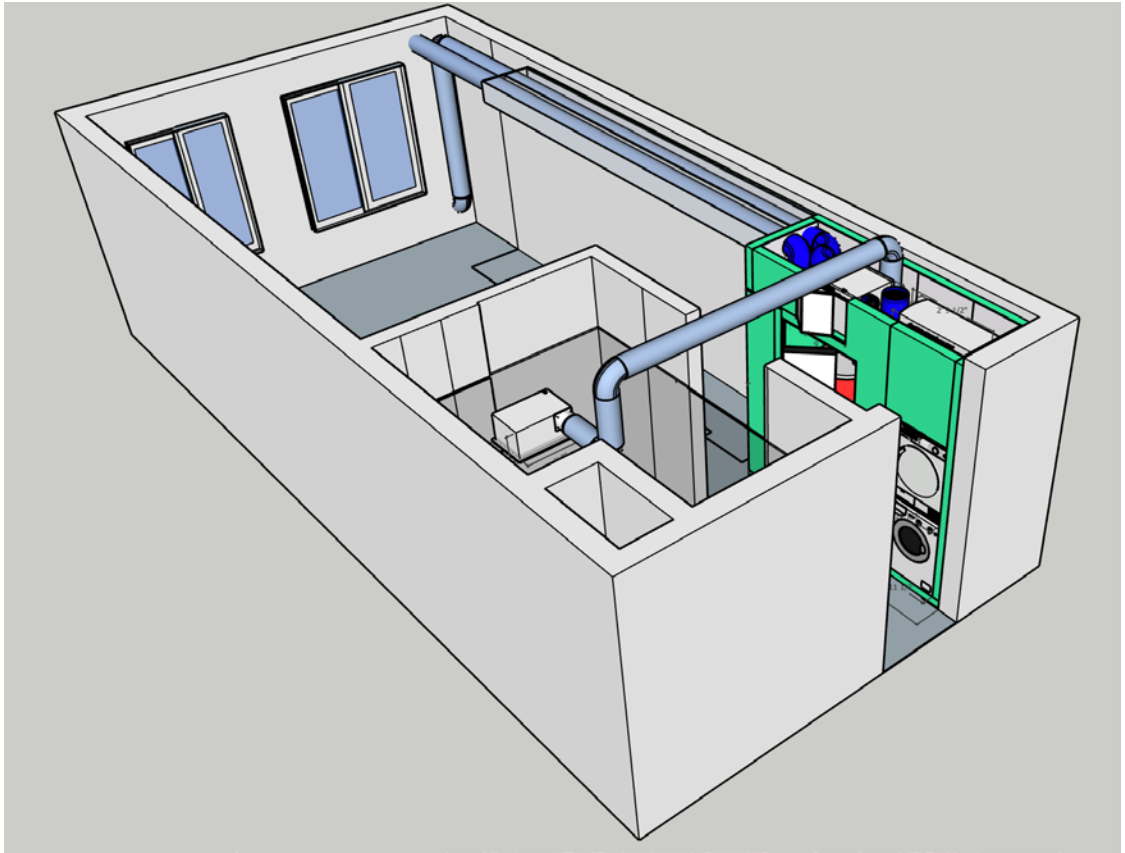
Energy Efficiency and DER in Off-Site: Possible Pathways for Energy Efficiency Integration



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

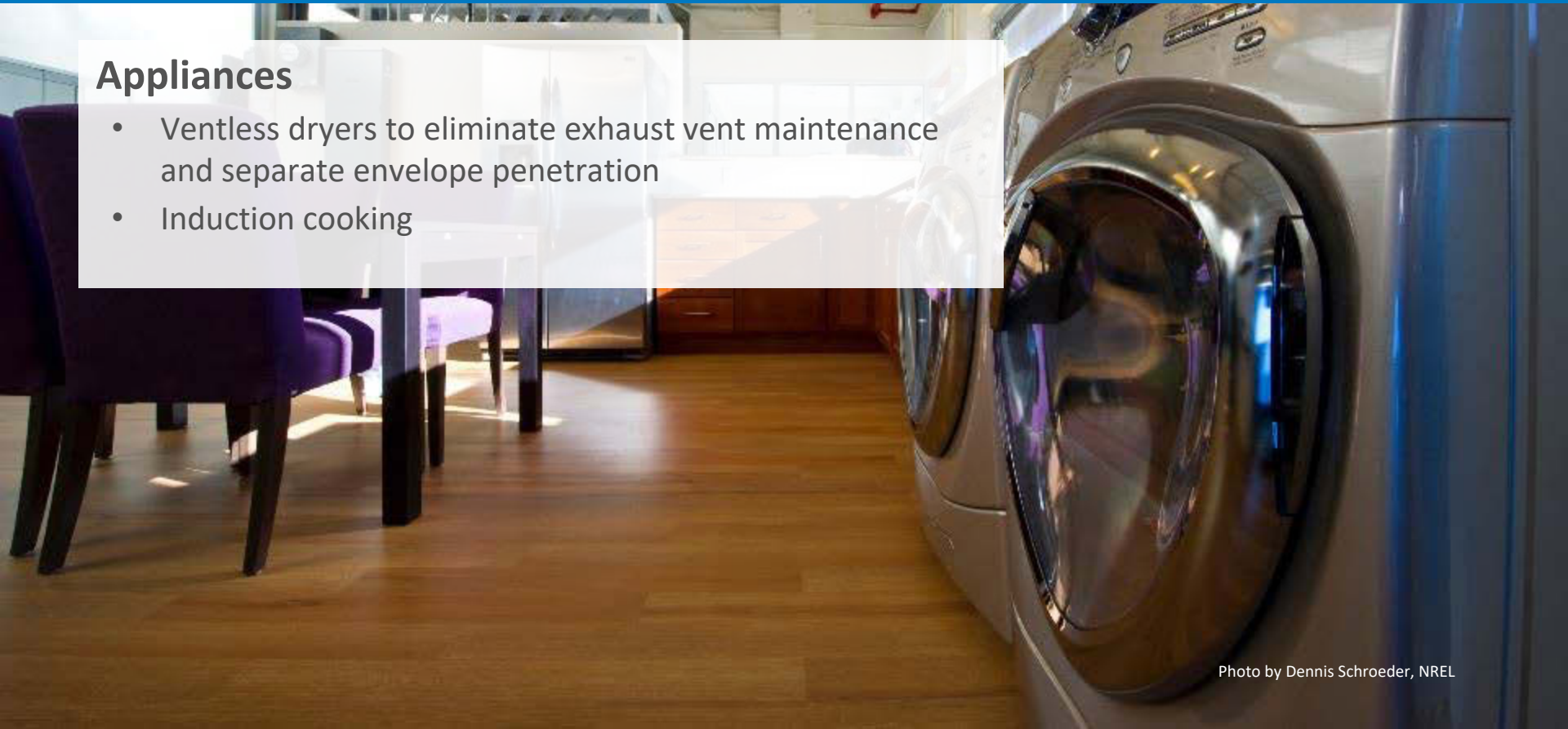


Shared Development Integrated Platform for HVAC Pod

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

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



Appliances

- Ventless dryers to eliminate exhaust vent maintenance and separate envelope penetration
- Induction cooking

Photo by Dennis Schroeder, NREL

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

Image: Wasatch Group

Renewables and Storage

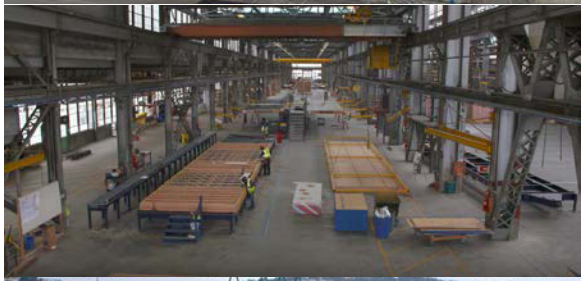
- Single meter to enable large-scale PV, with unit submetering
- Modular electrical room(s) with battery UPS and demand management
- Facade rainscreen and rooftop PV installed off-site
- In-unit battery storage for demand management and backup UPS
- **Document cost-savings pathways for replication**

"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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