"Not So Difficult" Approaches for Building Science Education

Patrick H. Huelman
University of Minnesota
&
Samuel Taylor
Consultant

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Driving Goal

- To improve building science education
  - Quantity
  - Quality
- In degree programs for building professionals
  - Associate
  - Undergraduate
  - Professional
  - Graduate

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Desired Outcome

- To ensure all students in building design, engineering, construction, and operations will graduate with:
  - a substantive “building science fundamentals” course early in their program,
  - solid “building science” concepts infused into their traditional courses, and
  - access to specialized, in-depth building science coursework.

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Mission of Joint Committee for Building Science Education

- Support transformation of the education and training of the design and construction industry, such that its professionals:
  - Are educated, trained, and certified in building science and related advanced design and construction management practices;
  - Can routinely design, build (renovate and fix), and operate quality, high performance buildings that are safe, healthy, durable, comfortable and very energy efficient; and
  - Will provide the highest value to their clients.

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Background

- Toronto (ASTM/NIBS/JCBSE) Workshop and previous DOE & HUD workshops identified:
  - Strong interest in building science education,
  - Good examples of current building science programs,
  - Solid existing building science teaching resources, but
  - Substantive academia constraints and challenges.
- Subsequent focus on potential solutions:
  - Move from addition to integration,
  - Move from stand alone to infusion,
  - Move from “easy button” to “not so difficult”.

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Important Themes

- Using a broad definition for "building sciences".
- Focus => Building science KSA's needed to plan, design, analyze, construct/renovate, and commission quality, high-performance buildings.
- Priority => Health, Safety, Durability, IAQ
  - First: Ensure no harm and no lawsuits;
  - Everything else (including daylighting, passive, green, sustainability) is second to, and/or must fit under this overarching priority.

Note: Core competencies for A/E Firm New Hires and DOE BSE Guidelines are available as handouts on table.

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Pathways for Success

- Support infusion of building science into traditional coursework and teaching resources,
- Promote a dedicated building science fundamentals course, and
- Encourage special higher level building science technical electives.

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Pathways for Success

- Provide easy access to building science resources
  - Promote excellence in building science teaching texts and support materials.
- Ensure best practices
  - Up-to-date access to research results
  - Connection to real world applications.
- Support graduate building science programs to increase future teaching capacity.
- Support & Expand building science experiential learning (RTZ) & pair to academic learning

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Great Progress (Post-Toronto)

- Affirming opportunities for "infusion"
  - Traditional courses; associated teaching resources
- Quality resources for teaching building science
  - Currently available or under development
- Improved access to building science research & best practices
  - DOE Building America Solution Center
  - Other: ASHRAE, NIBS, BSC, BSL, Joint Committee
- Excellent Experiential Learning Opportunities
  - Race to Zero, etc.

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Prioritization of Building Science

Key Assumptions

- Priority building science requirements
  - Health & safety, building durability, IAQ
- Priority damage functions (buildings & people)
  - Fire, smoke, and structure
    - critical, but addressed by codes and established practice
  - Moisture Management (Water, Water, and Water)!
    - critical, but currently underrepresented
  - Indoor Environmental Quality
- Effectively dealing with damage functions
  - risk tolerant designs and work procedures (e.g., QM)

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Conveying Key Building Science Concepts
Heat & Mass Transfer/Moisture Transport/IAQ

- Can critical concepts be fit into existing courses?
  - Heat transfer, 2nd Law of Thermodynamics (simplified)
  - Psychrometrics, relative humidity (RH), dew point
  - Prioritized moisture transport mechanisms
  - Requirements for air flow
  - Functions of the enclosure; esp. environmental separation
  - Continuity of control layers; verification with pen test
  - Understanding hygrothermal performance of enclosures, including performance consequences of material/placement
  - HVAC systems; esp. ventilation and make-up air
- Within one or two modules is a huge challenge?
  - Currently a “work in progress”, but has been done!

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Building Science Resources
(Partial Listing)

- Key Textbooks/References
  - ASHRAE Handbook of Fundamentals
  - High Performance Enclosures: Straube, J.
  - Understanding Psychrometrics: Gatley, D.
  - Water in Buildings: Rose, W.
  - Currently under development
    - Building Science Fundamentals: Lstiburek, J.
    - Building Science for Building Enclosures: Straube, J. & Burnett, E. 2nd Edition

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Building Science Resources
(Partial Listing)

- Online Resources
  - DOE Building America Solution Center
    - https://basc.pnnl.gov/
  - Building Science Corporation
    - www.BuildingScience.com/Information
  - Building Science Labs
    - www.buildingsciencelabs.com/the-library/
  - Joint Committee Website
    - www.BuildingScienceEducation.net
  - SBSE Website
    - www.sbse.org/resources/

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Building Science Infusion & Fundamentals (Research Underway)

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- Step 1: Identify Traditional Target Courses
  - Obtain syllabi from leading schools
  - Identify required & recommended textbooks
  - Identify supplemental teaching materials
  - Review for gaps in key building science topics
  - Identify possible approaches to convey key concepts
  - Initial test of infusion approaches (work in progress)

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Building Science Infusion & Fundamentals (Research Underway)

- Step 2: Review Teaching Materials for Courses
  - Work with key publishers to obtain identified texts
    - Wiley
    - Pearson/Prentiss Hall
    - ASHRAE
  - Review textbooks for treatment of critical building science topics
  - Review textbooks and online resources for supplemental building science materials

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- Step 3: Support Modification to Courses & Texts
  - Work with publishers and authors to identify process/ timelines for updating text or supplemental materials
  - Work with authors of building science resources
    - within texts, articles, supplemental materials
    - identify gaps that need to be filled by new resources
  - Need to integrate "best treatment" of key concepts into traditional modules (or for adding new modules)

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- Step 4: Process to Enhance Traditional Resources
  - Peer review of common textbooks
    - identify opportunities for enhancements, clarifications, corrections, etc.
  - More frequent printings of textbooks
    - opportunity for building science supplements
  - Update/expand online supplemental material
  - Publish peer-reviewed supplements on the JCBSE website

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Priority Targets for Building Science Infusion

- Environmental Controls/Systems I & II
  - Typically touches on heat transfer and air flow
  - Generally includes discussion of RH & IAQ
  - Popular references/texts include:
    - Mechanical & Electrical Equipment for Builings: Grondzik, W., Kwok, A., Stein, B., Reynolds, J.
    - Heating, Cooling, Lighting: Sustainable Design Methods for Architects: Lechner, N.

Priority Targets for Building Science Infusion

- Materials & Methods I & II (aka Construction Technologies I & II)
  - Typically touches on enclosure design
  - Can include discussion of moisture, RH
  - Popular references/texts include:
    - Building Construction: Mehta, M.
    - Building Construction Illustrated: Ching, F.
    - Fundamentals of Building Construction: Allen, E., Iano, J.

Priority Targets for Building Science Infusion

- Other Potential Course Targets
  - Construction Documentation
  - Construction Project Management
  - Systems Integration/Synthesis
  - Sustainable Design

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Building Science Fundamentals

Dedicated Stand Alone Course

- Requirement or technical elective
- Provides adequate coverage of key concepts & principles
  - Heat & mass transfer
  - Hygrothermal performance of enclosures
  - HVAC, IAQ, etc.
- Variations have been taught at:
  - U-MN, U-IL, Waterloo, Penn State, Leuven, etc.
- Popular textbooks & resources
  - High Performance Enclosures
  - ASHRAE Handbook of Fundamentals
  - Building Science for Building Enclosures
  - Online Articles: BSC, BSL, BA Solution Center, etc.

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Building Science Fundamentals
U-MN "Hygrothermal" Experience

- Establish Context, Perspective, and Principles
  - Lstiburek: "5 Fundamental Changes"
- Module 1: Heat Transfer
  - Assumes prerequisite modules (incl. labs) on heat transfer, psychrometrics, etc.
  - Temperature profile (hand calcs/spreadsheet)
- Module 2: Moisture Transport
  - Enhanced Glaser (Dew Point) Method (spreadsheet)
- Module 3: Material Storage
  - 1-D coupled heat & moisture analysis (WUFI software)

Note: This approach was successfully applied by RTZ team.

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DOE Race to Zero

Building Science Experiential Learning

- To date, 54 schools, 100 teams, and several hundred students and faculty have participated
  - Each RTZ team has participated in a mandatory "Building Science Fundamentals" training session.
  - All designs must meet DOE ZERH requirements.
  - Homes that are so efficient a small renewable system can offset all or most energy needs.
- Subscribe your "potential interest" for 2017 RTZ
  - Review the benefits
  - Access to key resources

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Expanding Building Science Experiential Learning

- Imagine the Impact
  - If the RTZ building science resources were available for the other student competitions.
  - Shouldn't their designs reflect this level of building science and best practices?

- Next Penn State will address "**Building Science Education as an Integral Part of Project-Based/ Experiential Learning**"

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Good News

- Significant progress is being made towards larger building science education goals and outcomes.
- Several short-term successes:
  - Demonstrated that it is “not so difficult” to infuse building science into existing courses,
  - Uncovered a wealth of building science teaching resources that are (or will be) readily available,
  - Several experiential learning opportunities to reinforce building science best practices.

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Our Challenge

- Short-Term Objectives
  - Continue to support “building science infusion”
  - Increase, peer review, improve, share building science resources (need qualified peer reviewers)
  - Expand experiential learning opportunities
- Medium-Term Targets
  - Push for revision of curriculum, credentials, accreditation, etc. to incorporate building science
- Long-Term Goals
  - Support graduate education and research in building science, so we will have great teachers and mentors

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Thank You

- Be sure to visit the JCBSE website
  - www. BuildingScienceEducation.net
- Contact information
  - Patrick H. Huelman
    - University of Minnesota
    - 203 Kaufert Lab; 2004 Folwell Ave,
    - St. Paul, MN 55108
    - 612-624-1286; phuelman@umn.edu
  - Samuel Taylor
    - Energy & Resource Efficiency
    - Samuel.taylor.sr@gmail.com

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DOE Race to Zero

Key Benefits (video)

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- **ASTM**
- **JCBSE**

Proficiency Levels of Design/Construction Disciplines vs. Key Courses/Skills

Draft Example

Key "Building Science" Courses For Quality, High Performance Buildings	Engineering				Design		Construction Management	Other - Sustainability /Housing Studies/ etc.
	Civil	Mech.	Arch. Engr.	Other - Material Science	Architecture - Bldg. Perf., Other	Other -		
Accreditation	**ABET**				**NAAB, other**		**ACCE**	**Other**
Building Science Fundamentals (*Building Science 101*)								
Building Enclosure Characterization & Optimization (*Hygrothermal Analysis; Structure & Control Layers*)								
Material Science for Buildings								
HVAC (MEP/other Building Services) Design, Analysis & Installation								
Indoor Air Quality								
Building Performance Tools & Analysis								
Advanced Design/ Construction Documentation (*detailing, scopes-of-work, specifications, etc.*)								
Quality Management/ Commissioning								
Integrated Design Process/ Multi-Disciplinary Project Management								
Systems Engineering/Integration- (ability to assess system implications)								
Other, e.g., • Facility operations & management • Testing; forensics • BIM, Etc.								

NOTE: Proficiency levels are initially being addressed in terms of Bloom's Taxonomy e.g., (1 = Remember (knowledge), 2 = Understand (comprehension), 3 = Apply (application), 4 = Analyze (analysis), 5 = Evaluate (synthesis), 6 = Create (design). . Skills descriptions can be expanded in terms of desired learning outcomes supporting specific job related core competencies.

Hygrothermal Analysis: From Intuition to Calculations to Simulation (DRAFT)

Patrick Huelman, University of Minnesota – Building Science & Technology
3/1/16

Step 1. Establish Context, Perspective, & Principles

Supporting Materials: *BSI-039 Five Things – Lstiburek, ASHRAE Handbook*

a. Opening Lab Discussion built on the "Five Fundamental Changes"
b. Building Science Primer
- Introduction to Heat, Air, and Moisture (HAM)
- Basics of Moisture Transport (Liquid and Vapor)
- Functions of the enclosure, environmental separation, and control layers

c. Students select a common wall system
d. Quick Check: Can moisture susceptible materials get wet (by water or condensation)?
If they get wet, can they dry (primarily by vapor diffusion)?

Step 2. Heat Transfer & Thermal Profiles

Supporting Materials*: ASHRAE Handbook, High Performance Enclosures – Straube*

a. Review fundamentals of heat transfer in buildings
b. Develop a temperature profile through the assembly layers (both cavity & framing)
- must select boundary conditions (indoor & outdoor)
  - indoor temperature and relative humidity
  - winter and summer exterior design temperatures are probably too severe
  - monthly average exterior temperature is a reasonable approach
  - depending on material storage capacity a longer average might be used
- simplest approach is to guess the most likely condensation plane and solve for the temperature at that location only
- more detailed approach is to calculate the temperature at each interface based on the temperature drop across each material

c. Compare surface temperature(s) to interior or exterior dewpoint temperatures
- recognize limitation: it assumes the indoor/outdoor air can reach that surface
- ignores liquid transport, phase change, and material storage

Step 3. Psychrometrics & Vapor Pressure Profiles

Support Materials: *Understanding Psychrometrics – Gatley, Water in Buildings – Rose*

a. Review principles and terminology
b. How to use the psychrometric tables, charts, and equations
c. Concept of vapor pressure profile through the assembly layers (cavity and framing)
- use temperature profile through layers above to calculate a saturated vapor pressure condition for each interface
- find the vapor pressure drop across each layer to get calculated vapor pressure
- compare calculated to saturated vapor pressures to determine %RH at each surface
- if greater than 100%, reset that surface to the saturated pressure and recalculate

c. Is there a condensation potential (100% RH) at any surface?
- recognize limitation: this assumes there is no air leakage
- ignores liquid transport, phase change, and material storage

Step 4. Materials Storage & Hygrothermal Modeling

Supporting Materials: *Building Science for Building Enclosures - Straube & Burnett*
Software: *WUFI – ORNL/Fraunhofer IBP*

a. Review states of moisture, material storage, sorption isotherms, etc.

b. Now calculate the vapor flow to and away from the surface of concern; the difference will be net accumulation; compare accumulation potential over time to material storage capacity

c. Move to dynamic hygrothermal simulation with WUFI (or other similar programs)

- recognize limitations: 1-D analysis reflects diffusion, water transport, and material storage; however, without using moisture sources/sinks the flow of air and water between layers is ignored

Step 5: Wrap-up & Analysis

Supporting Material: *BSI-001 The Perfect Wall – Lstiburek*

a. Review strengths and limitations of each approach

b. Compare and contrast results from each approach

c. Step away from the edge – the beauty of exterior insulation!

Key Resources:

ASHRAE Handbook of Fundamentals. ASHRAE. 2013
Building Science for Building Enclosures. John Straube & Eric Burnett. 2005
B[i]SI Series. Building Science Corporation. Available at buildingscience.com
Builder Guides. Joseph Lstiburek. Building Science Press. Available at buildingscience.com
High Performance Enclosures. John Straube. Building Science Press, 2012
Understanding Psychrometrics. Donald Gatley. ASHRAE. 2004
Water in Buildings. William Rose. Wiley Press. 2005
WUFI Pro 5.3 Education. Oak Ridge National Laboratory/Fraunhofer IBP. 2015

Contact Information

Patrick H. Huelman, University of Minnesota
203 Kaufert Lab, 2004 Folwell Avenue
St. Paul, MN 55108
612-624-1286
phuelman@umn.edu

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[i] The hygrothermal analysis steps are used in the U MN advanced building science class and also were used for the US DOE Race to Zero Envelope Durability analysis. In general, Step 1 and introductory material for Steps 2 and 3 can be incorporated into such traditional courses as Materials & Methods (Construction Technology) and Environmental Systems.

Requirements for Acquired Building Science Skills (e.g., KSA's, Core Competencies)

The Joint Committee on Building Science Education, along with our partners in the US Department of Energy (DOE) and other academic organizations, recognizes the need to assess the building science proficiency of design and construction professionals and the effectiveness of curricula and teaching resources in developing that proficiency. The Joint Committee has posted a matrix on building science proficiency requirements for academic disciplines supporting the design/construction profession. DOE has published Building Science Education Guidelines. In Canada and Europe, there are certification requirements for Building Science proficiency. For example, the Ontario Building Envelope Enclosure Council provides a certification for a building science professional (http://obec.on.ca/BSSO/default.asp).

Also, a number of A/E firms have developed their own requirements. Below is an example of one engineering firm's preliminary (draft) list of requirements for a building science professional. This particular engineering firm designs, investigates, and rehabilitates structures and building enclosures. Other firms involved in different aspects of the planning, design, analysis, construction or renovation of quality, high performance residential, commercial and institutional buildings may have a different set of desired KSA's.

"For an individual to be prepared for the building science profession, the following skill set is desirable on top of the standard requirements for accreditation and licensure for architects and engineers:

- **An understanding and competency in building physics** (heat, air and moisture transfer, including an understanding and ability to evaluate heat flow under each heat transfer mechanism (conduction, convection and radiation), an understanding of air flow and moisture-laden and contaminant laden air transport and understanding of diffusive vapor transport, and an understanding of wetting and drying mechanisms (i.e. all of the necessary building physics fundamentals and theory -- building scientists should be capable of relating software results back to first principles).
- **Understanding of psychrometrics** and how to use the chart to understand the HVAC process as well as to determine all of the parameters of importance for building physics from the chart. They must also be able to calculate and identify critical dewpoint conditions.
- **Ability to run hygrothermal modeling tools** (like WUFI) and heat transfer analysis (THERM, HEAT and HEAT 3-D), and equally as important, translate the results and be able to explain the results as they apply to the real world.
- An **understanding of architecture, architectural engineering, structural engineering, building enclosure design, building technology, and aspects of the other building sciences** outside of building physics (lighting and daylighting, acoustics, fire and smoke control, blast and hardening of structures for security measures) and the interrelation to building physics.
- **Understanding of the four major building enclosure systems** and how they are interrelated and tie-ins between materials and systems for the rainwater management system (waterproofing and flashings), air barrier system, thermal barrier system, and diffusive vapor flow control systems, as well as how building physics relate to these systems.
- **Ability to draw design details** for residential and commercial structures, tie-ins, and explain how each layer of the system is engineered to deal with a certain aspect of building physics, and where the details have to compromise to accommodate the predominant feature needed (say water tightness).
- **Understanding of commercial and residential construction**, including concrete-framed, metal-framed (structural steel and light-gauge framing), and wood-framed structures.
- **Understanding of testing equipment/tool**s used on-site to test flow paths for air, water and thermal transfer, including water infiltration testing (spray rack and nozzle), pressure gauges, theatrical smoke, blower doors, temperature and relative humidity gauges, and data loggers along with an understanding of how to interpret the results of the tests
- **Understanding of HVAC interaction with the building enclosure**, the enclosures impact on lighting and daylighting choices, and the impact of varying percentages of fenestration.
- **Ability to analyze building performance**, including the ability to run a refined and more accurate energy model, understanding parameters like the effect of adjacent buildings, the effect of space versus occupancy in deciding how much space needs to be conditioned and lit, versus "dead" space, and potential impacts of climate change, all related and tied back into the fundamentals of building physics".

University of Minnesota
Team OptiMN
“OptiMN Impact Home”

Project Summary

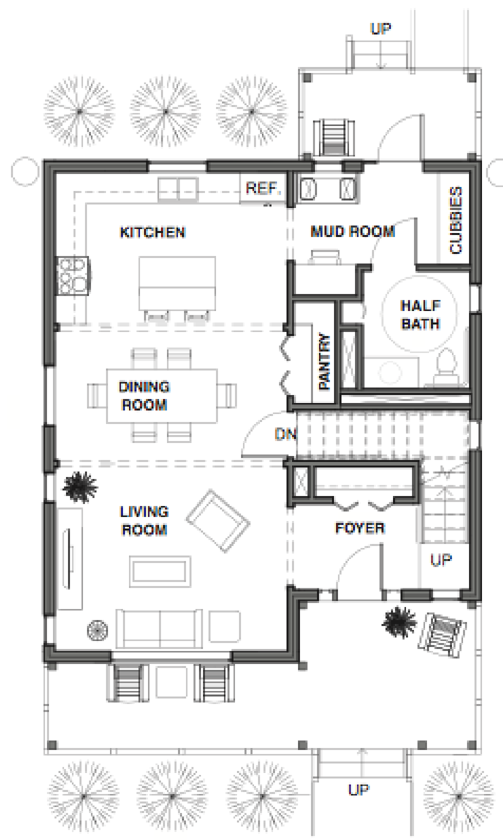
Designed to fit on the majority of North Minneapolis infill lots, the OptiMN Impact Home is a collaborative project between the University of Minnesota and Urban Homeworks. The overarching goal was a flexible, high-performance, energy-efficient, and affordable house that can be easily built by Urban Homeworks and purchased by eligible low-income residents of North Minneapolis through the Green Homes North program.

Relevance to the Goals of the Competition

The Impact Home meets both the DOE Zero Energy Ready Home criteria (per competition guidelines), as well as the Green Homes North program criteria established by the city of Minneapolis. It demonstrates that a high-performance, zero energy ready home can be both attractive and affordable.

Design Strategy and Key Points

- **Enclosure**: Durable and robust building systems using a hybrid 2x4 wall with exterior insulation; cathedral truss roof with exterior insulation; high-performance windows; and exterior foundation insulation; airtight construction.
- **HVAC**: High-performance integrated space and water heating system with inverter heat pump for cooling/dehumidification, energy recovery ventilator, and high-efficiency filter – all delivered through a compact, small duct distribution system.
- **IAQ**: Design strategy focused on pollution avoidance, source-point exhaust, continuous ventilation, and consistent distribution of fresh and filtered air to all habitable rooms.



Project Data

- Location: Minneapolis, MN
- 2009 IECC Climate Zone: 6
- Square Feet: 2,544 (including unfinished lower level)
- Number of Stories: 2
- Number of Bedrooms: 3
- Number of Bathrooms: 1.5
- HERS Score: 32 w/o PV; 0 w/ PV
- Estimated Monthly Energy Costs: $93 w/o PV; $10 w/ PV

Technical Specifications

- Slab Insulation = R-10; Foundation Insulation = R-15
- Wall Insulation = R-30; Roof Insulation = R-50
- Airtightness Target = 1.0 ACH@50Pa
- Windows = 0.27 U-Value; 0.20 SHGC
- Heating/Cooling/DHW Specifications = 95% CAE; 17 SEER
- Energy Recovery Ventilation = 60 to 120 cfm w/70% SRE

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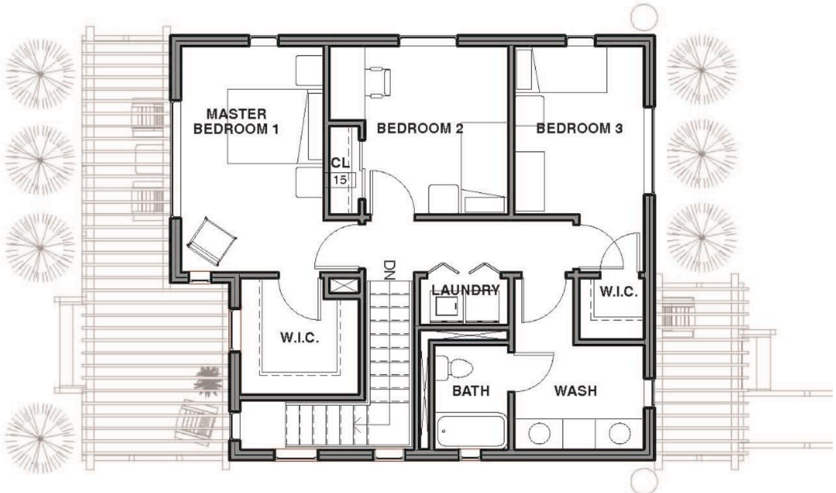
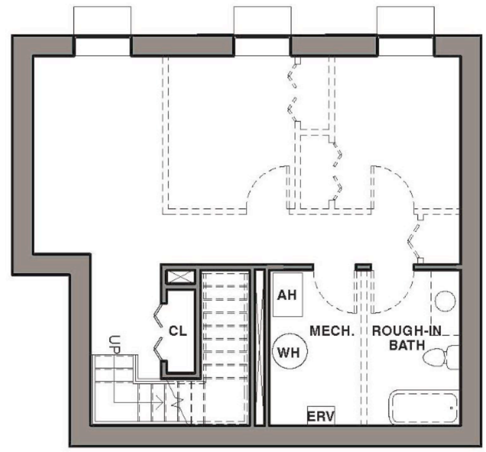
"OptiMN Impact Home"

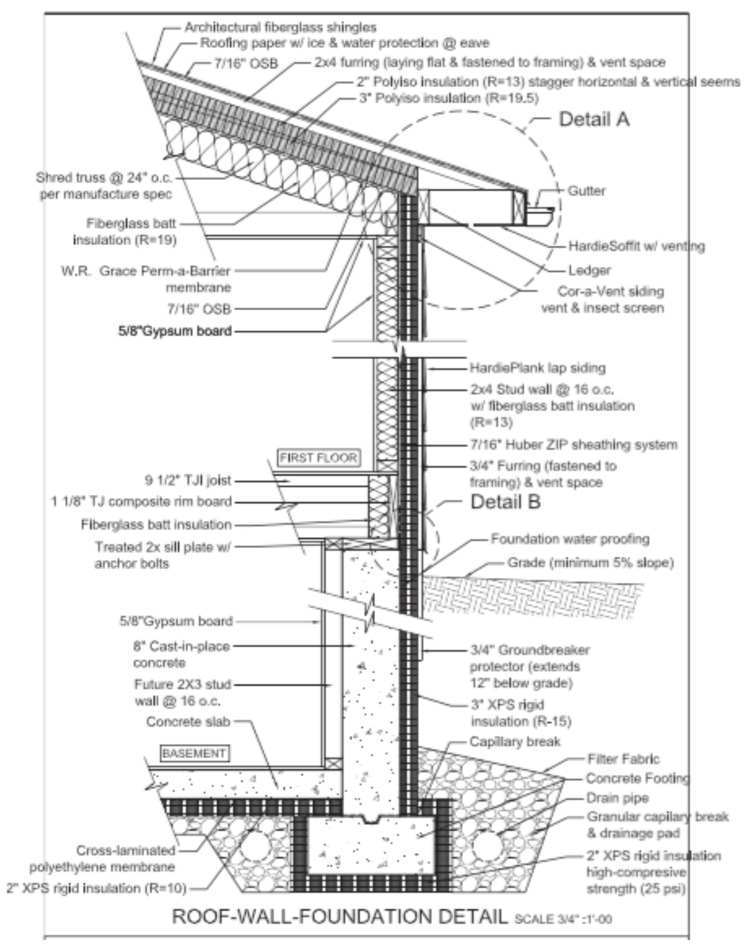


Second Story Floor Plan



Lower Level Floor Plan

Wall Detail



Roof Detail