Innovation in Renovation

Optimizing interior insulation application workflow

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https://www.reddit.com
Amsterdam Canal house
http://elles.nl
Insulate

Lower energy bills
Sustainable living
Protected building

No exterior interventions

Limited space
Protected building

Interior insulation application
Insulation workflow

Current on site workflow

Measurement  Material selection  Procurement  Sizing  Preparation  Fitting  Finish
Problem statement

Varying interior treatments

Occupant discomfort

On-site time

Risk of condensation

Space required
Research question

How can the advancements in insulation material and technologies help to optimize the energy renovation process of interior envelope?
Aim

To create a model workflow for the renovation process of existing protected buildings by adopting super insulation material and technological advancements to aid production and assembly.
Research methodology

Phase 1: Foundation / Literature study
Phase 2: Material study
Phase 3: Digitalization
Phase 4: Product design
Phase 5: Validation
Proposed workflow

Measurement  Processing  Material selection  Design and layout  fabrication  Fitting
Area of optimization

- Material
- Process innovation
- Product design
Material

Silica aerogel under the microscope | http://www.aerogel.org
Measures of energy efficiency

Renewable energy system
Insulation of envelope
 Efficient fixtures
Summer heat control
Natural light and ventilation
Efficient equipment
### Insulation of envelope

**Heating energy reduction**

<table>
<thead>
<tr>
<th></th>
<th>Thermal load (kwh/m²)</th>
<th>Heating energy (kwh/m²)</th>
<th>Heat reduction</th>
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<tbody>
<tr>
<td><strong>At 60% WWR</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uninsulated wall with single glazing</td>
<td>140.13</td>
<td>129.73</td>
<td></td>
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<tr>
<td>Uninsulated wall with double glazing</td>
<td>104.57</td>
<td>94.54</td>
<td>35.19</td>
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<tr>
<td>Insulated wall with double glazing</td>
<td>71.4</td>
<td>61.13</td>
<td>33.41</td>
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<tr>
<td><strong>At 40% WWR</strong></td>
<td></td>
<td></td>
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<tr>
<td>Insulated wall with double glazing</td>
<td>62.00</td>
<td>54.00</td>
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</tr>
<tr>
<td><strong>At 80% WWR</strong></td>
<td></td>
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<tr>
<td>Insulated wall with double glazing</td>
<td>81.29</td>
<td>68.67</td>
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</table>
Common wall insulation material

- Batt/roll
- Rigid
- Spray foam
- Loose fill
Superinsulation material

Vacuum Insulation panel
Aerogel blanket
Aerogel boards
Aerogel granules
Aerogel plaster
Thermal conductivity

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity (W/mK)</th>
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</thead>
<tbody>
<tr>
<td>Wood fibre</td>
<td>0.005</td>
</tr>
<tr>
<td>perlite</td>
<td>0.015</td>
</tr>
<tr>
<td>Cellulose fibres</td>
<td>0.02</td>
</tr>
<tr>
<td>Hemp</td>
<td>0.025</td>
</tr>
<tr>
<td>Extruded Polystyrene (XPS)</td>
<td>0.03</td>
</tr>
<tr>
<td>Rock wool</td>
<td>0.035</td>
</tr>
<tr>
<td>Expanded Polystyrene (EPS)</td>
<td>0.04</td>
</tr>
<tr>
<td>Glass wool</td>
<td>0.045</td>
</tr>
<tr>
<td>Polyurethane rigid foam (PUR)</td>
<td>0.05</td>
</tr>
<tr>
<td>Phenolic foam</td>
<td>0.05</td>
</tr>
<tr>
<td>aerogel</td>
<td>0.05</td>
</tr>
<tr>
<td>VIP</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Insulation material

Relative thickness

- 140mm wood fibre
- 100mm EPS/XPS
- 80mm PUR
- 40mm Aerogel
- 20mm VIP
Insulation material

Advantages over common insulation material

• 50% - 80% space saving due to slimmer profiles
• Material saving
• High thermal performance
• Non-toxic content
Superinsulators

Material properties

- Thermal performance
- Fire resistance
- Vapour permeability
- Physical form
- Area of application
- Average life and end-of-life
- Challenges
Vacuum Insulation Panel (VIP)

**Description**
Vacuum Insulation panels are super insulation that have a highly porous rigid core, generally of fumed silica, and wrapped in an gas-tight envelope from which air has been evacuated. These rigid panels: 10mm to 50mm thick and commercially available in sizes of 1000mm/ 500 mm x 600mm. They are suitable for use on exterior walls, interior walls, cavity space, floors an compact roofs, door and window reveals.

** Thermal performance**: 0.007 W/m

**Flameproof**: recyclable core/ non-recyclable envelope

**Life expectancy**: 25 Years

**Air and water tight**: protective membrane

finish with tough impact boards

Rigid panel

Aerogel Blankets

**Description**
Aerogel blankets are available in 5mm or 10mm thickness as flexible blankets in the 10 meter rolls that are 1470mm wide. The aerogel component of SpaceSoft® is synthetic amorphous (non-crystalline) silica with PET/glass fibre and additives.

**Thermal performance**: 0.015 W/mK

**Handle with care**: mechanical fasteners

**Life expectancy**: 50 Years

**C-s 1,0**: Difficult to ignite

flexible blanket

air tight, water tight

water vapour perme-

finish with tough impact layer - gypsum, wood fiber, direct

0.015

W/mK

Thermal performance
Aerogel Blankets

Description
The boards are aerogel blanket that come finished with 3mm Magnesium oxide boards. These are available in the size of 2400mm x 1000mm rigid board. They are suitable for use on exterior walls, interior walls, cavity space, floors an compact roofs, door and window reveals.

Thermal performance:
0.016 W/mK

Life expectancy:
50 Years

Aerogel plaster

Description
Lightweight Aerogel granulate is the primary additive used in this high-performance lime-based insulating plaster. Aerogel plasters are not restricted by shape or size of the surface. Available as dry premix with cement, the render can be applied to the required thickness.

Thermal performance:
0.028 W/mK

Life expectancy:
20 Years
Aerogel granules

Description
Aerogels granules are 1mm to 5mm in size and can be loose filled in any container. Most commonly used in windows or skylight due to the high light transmission value.

- Loose granules
- Finish with casing friendly material.
- Air tight, water tight, water vapour permeable.
- 0.019 W/mK Thermal performance
- Keep dry
- Lose fill cavity spaces
- 50 Years Life expectancy
- Non flammable
- Non additive, grains directly reused
Interior insulation

Thermal performance with respect to thickness

![Graph showing U-value vs. Thickness for different materials: Vacuum insulation panel, Aerogel blanket, Aerogel granules, Aerogel board, Aerogel plaster. The LT heating threshold and Building decree threshold are indicated.]
Conclusion

Material properties

- VIP’s deliver lowest thermal conductivity and subsequently least thickness.
- The rigid panels can not be altered once produced.
- Their fragile nature demands extra care during handling.

- Aerogel blankets are the more sustainable material option amongst the superinsulators.
- Aerogel boards perform like blankets but are not suitable due to use of adhesive.
- Aerogel granules are best suitable for infill in transparent elements.
Process innovation
Process innovation

Data capture → Process to digital model → Layout of panels → Virtual reality experience → Number and sizes for production
Process innovation

Equipment for data capture

Terrestrial laser scanning (TLS)  Total/Multi-Station  Global Navigation Satellite System  Simultaneous Localisation and Mapping  Structure from Motion Photogrammetry
Process innovation

Point cloud to BIM model
Process innovation

Software support

Autodesk Revit™
McNeel Rhinoceros™
Geomagic wrap™
MeshLab - mesh™
CloudCompare™
Process innovation

Parametric tessellation for optimum layout
Process innovation

Virtual environment
Process innovation

Virtual environment
Process innovation

Conclusions

• Laser Scanning (TLS) allows for rapid interior surveying
• For a thorough scan, it is recommended to take multiple scans from different positions
• Scan resolution determines the level of detail captured
• Management of the acquired points is done through specialised software to create BIM model that require extra knowledge and skill
• In the future interoperability with BIM model and data exchange could be reached
• Virtual reality experience integrates occupants opinions into the final output of renovation
• It is a crucial step to aid accurately dimensioned fabrication
Product design

Prefabricated façade panels | https://www.taylormaxwell.co.uk/offsite-components
Product design

- Prefabrication
- Sandwich panel
- Demount and disassemble
- Adaptive
• Thematic diagram?
Product design

Design option 1 – shiplap joinery

- Wooden studs (60mm)
- Mechanical fasteners (screws)
- Insulation (20mm)
- Finish board (10mm)
Product design

Design option 2 – tongue and groove joinery

- Backing board (5mm)
- Insulation (20mm)
- C-sections for fixing
- Finish board (10mm)
Product design

Design option 3 - shiplap joinery

- Insulation (20mm)
- Steel / PVC channel
- Z-clips
- Finish board (10mm)
Product design

Comparison

Design option 1
- Easy to assemble and install
- Wooden frame adds to the thickness of the panel

Design option 2
- Discontinuous smaller C-sections reduce thermal bridges
- Too many elements make the assembly complex
- The backing material is not functionally required

Design option 3
- Slimmest section of the panel
- Lesser area of contact for thermal bridging
- Easier to assemble and disassemble
Product design

Global solution

Vacuum insulation panel

Channel

Finish board
Product design

Global solution

- Aerogel blanket
- Vapour barrier layer
- Channel
- Finish board
Product design

Additional bracing
Product design

Adaptability
Product design

Adaptability- changing skins
Production process
Production process
Product design

Conclusion

• A design approach of prefabricating a finished insulated wall panel to save on site time for fixing each element

• No glue or adhesive use make the product more complex to manufacture but ensure re-usability of elements. Hence a longer life cycle

• The adaptive channel make it convenient to integrate the design with different insulation material.

• Stylize the finish as per user requirement.
Demonstration of workflow
Case study

Proposed workflow

Select case-study room → Laser scan for measurements → Process to digital model → Design and layout of panels
Demonstration room
Laser scanner setup

FARO Focus S
Demonstration room

Photographic capture
Demonstration room

Demonstration room as point clouds with stray noise
Demonstration room

Cropped to working area
Conversion to digital model

1. Export from FARO SCENE software as point cloud data
2. Import into a 3D modelling software
3. Use points as guides to draw over
4. Switch off point cloud for reconstructed model
Digital Model

Reconstruction in Revit
Digital Model

Reconstruction in Rhinoceros
Panel layout

1. Identify external wall surface to insulate
2. Divide surface in panels as per commercially available insulation sizes
3. Resolve fixtures, connections and edge joinery
4. Extract dimensions and send for production
Target surfaces
Surface division

Layout option 1 – standard sized VIP’s with filler insulation
Surface division

Layout option 1 – standard sized VIP’s with filler insulation
Surface division

Layout option 2 - custom sized insulation
Layout option 2 - custom sized insulation

20mm VIP

Finish board

767 mm

934 mm
Surface division

Layout remarks

- Commercially available size of VIP’s hence economical
- U value of 0.43 with 20mm XPS or 0.34 with 20mm aerogel blanket or 0.28 with 25mm thick section
- Aligning is more difficult due to fixed sizes

- Customized VIP’s of the required size hence expensive
- U value of 0.29 W/m2K with 20mm of VIP
- Finish boards aligned to existing patterns
Case study

Solving connections
Connections

Detail A : Edge detail

- Wall plaster
- 40mm Insulation
- Vapor barrier
- Channel
- 10mm Finish

Section plane
Connections

Detail A: corner connection in a butt joint assembly

- External wall
- Channel
- Z-clips
- 20mm Insulation
- 10mm Finish
Connections

Detail B : Window reveal

Window frame
Channel fixed to window frame
Sill reveal panel
Sill wall panel
20mm insulation layer
Wall plaster

Section plane
Connections

Detail B: window reveal

Window frame
10mm Finish
20mm XPS insulation
20mm VIP Insulation
Extern wall
Connections

Detail B: Skirting

- Wall panel slides on top of skirting
- Channel fixed to wall
- 15 mm skirting finish
- 10 mm insulation layer
- Existing skirting
Connections

Detail B: Skirting panel assembly sequence

10mm insulation strip  Channel  Skirting finish
Connections

Detail C: Pipes option a

- 10mm finish board
- 20mm Insulation
- Pipe existing
- Z-clips
- Channel fixed to wall
- Channel fixed to window frame
Connections

Detail B : Pipes option b

- Wall plaster
- 20mm Insulation
- Pipe
- Z-clips and spacer
- Channel fixed to wall
- 10mm Finish
Connections

Layout with option a and b

Visible pipes. Panel can slide behind existing pipes

Hidden pipes. Panel cover is offset to include pipes in a cavity.
Finishes
Visualization
Assembly Sequence
Assembly Sequence
Assembly Sequence
Assembly Sequence
Assembly Sequence
Assembly Sequence
Assembly Sequence
Assembly Sequence
Assembly Sequence
Assembly Sequence
Assembly Sequence
Assembly Sequence
Assembly Sequence
Mock up
Case study

Conclusion

• Laser scanning is a fast and accurate method for getting measurements.
• Creating a digital model from point cloud still requires development and machine learning
• Manual reconstruction lead to inaccurate measurements
• Typical connection details need to be modified as per site conditions
• Space constrains can help in material selection
• Budget constrains can help layout selection
• Visualizations and personalisation engages the occupants in the process
Research question

*How can the advancements in insulation material and technologies help to optimize the energy renovation process of interior envelope?*
Conclusion

• The process of insulation of the envelope has challenges of preparation, condensation, spaces and discomfort to overcome.
• Superinsulators save crucial floor space without compromising on the thermal performance. Current drawback is cost.
• Technological advancements with machine learning provide the means to automate process and reduce processing time. At the moment this can take longer than manual process.
• Processing need to be further optimized.
• Production techniques such as prefabrication decrease the onsite assembly time.
• Design for demounting disassembly makes the product complex but is important for a sustainable development.
• Best suitable for large scale mass renovation to justify the associated high costs.
• Save space with the material, measurement time, application time, material use and wastage.
Sustainability assessment

PEOPLE
• Reduce the impact on occupants by reducing the time spent on site
• Prefabrication so that no work would be done on site
• Involve the people on a digital platform to see the impact on the interior spaces
• Liberty to choose the aesthetics

PLANET
• insulation material assessed on its impact on environment.
• Current researches into making them bio based with natural alternatives (cellulose)
• None adhesives fixing makes elements easier to separate at the end of product life for recycling.
• Adaptable design promotes reusability of the same product in different conditions making the final design ‘one product fits all’.

PROFIT
• high cost of superinsulators and scanning equipment for a single household is not feasible.
• the high demand lowers the supply cost.
• Prefabricated adaptive design require lesser material, lesser labour cost and no demolition costs.
• Reusable elements reduce cost for new production.
• ‘One assembly line produces all’
Thank you
Innovation in Renovation

Optimizing interior insulation application workflow

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https://www.reddit.com
## Introduction

Energy Agreement for Sustainable Growth

<table>
<thead>
<tr>
<th>300,000</th>
<th>homes to be renovated by 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 -30%</td>
<td>increase in energy efficiency in renovation houses</td>
</tr>
<tr>
<td>Label B</td>
<td>average label for energy efficient social housing</td>
</tr>
</tbody>
</table>
Introduction

Current statistics

70% homes have energy label C or lesser

1% Existing building renovated every year
Research methodology

Phase 1

Foundation / Literature study

Energy renovation

Protected buildings

Research Question

Innovations in material and technology

measures

workflow

Traditional practices

challenges
Research methodology

Phase 2

Material study

Conventional insulation

Superinsulators

Performance

drawbacks

performance

challenges

Data sheets

Superinsulators performance data
Research methodology

Phase 3

Digitalization

Data capture

Data processing

Equipment

workflow

Digital model

Optimized layout

Production information

Number and size of insulation required
Research methodology

Phase 4

Product design

Insulated panel

Prefabricated

Demountable

disassembly

adaptable

Final product

Factory made, delivered and fixed
Research methodology

Phase 5: Validation

- Case study room
- Data capture
  - Data Processing
  - Optimized layout
  - Performance analysis

Conclusion: Answer to research question
Moisture risk | 20mm Vacuum Insulation

Case 1: 260mm brick wall
### Moisture risk | 20mm aerogel blanket + Vapor barrier

#### case 1: 260mm brick wall

**Thermal protection**

<table>
<thead>
<tr>
<th>Material</th>
<th>U Value (W/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior insulation</td>
<td>0.55</td>
</tr>
</tbody>
</table>

**Moisture proofing**

- No condensate

**Heat protection**

- Temperature amplitude damping: 6.2
- Phase shift: 11.2 h
- Thermal capacity inside: 58 kJ/m²K

**Temperature profile**

- Temperature and dew-point temperature in the component. The dew-point indicates the temperature, at which water vapour condensates. As long as the temperature of the component is everywhere above the dew-point temperature, no condensation occurs. If the curves have contact, condensation occurs at the corresponding position.

**Humidity**

- The temperature of the inside surface is 16.8°C leading to a relative humidity on the surface of 61%. Mould formation is not expected under these conditions.
- The following figure shows the relative humidity inside the component.
Product design

Thermal bridges – channel material

VIP with PVC channel

VIP with steel channel

VIP with steel channel with neoprene