Section 1 Techniques

1.1 Insulation and Thermal Bridges

Developer: Uli Neumann (University of Kassel – CESR)
Reviewer: Jan-Olof Dalenbäck (Chalmers University – EnerMa)

VIP – Vacuum Isolation Panels in Practice

- very low thermal conductivity? space saving (factor 5 … 10)
- application fields: floor, balcony, walls and ceilings with little scope
  (e. g. embrasures, dormers, connections, indoor insulation)
- high influence of thermal bridges
  in-between mounted elements
  ? very accurate mounting
  without any gaps indispensable
- special fixing-solution: dowels (glass-fibre)
  clamp elements at edge
- durability: up to 50 years (at room temperature),
  significant reduced by permanent humidity (‘protection’)
- VIPs nearly impermeable, but humidity transport via splices
- avoid punctiform pressure
- cost intensive; special handling? special-purpose solution
Contents

- Insulation materials and their features
- Insulation-systems for (Ultra)Low-Energy-Houses
- Special-purpose solutions: Vacuum-Insulation-Panels and Transparent Insulation in practice
- Thermal bridges
- Airtightness
- Exemplary solutions

Thermal Conductivity of Insulation Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity (λ) [W/m*K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural insulation materials</td>
<td></td>
</tr>
<tr>
<td>Mineral foam</td>
<td></td>
</tr>
<tr>
<td>Mineral wool (rockwool, glass wool)</td>
<td></td>
</tr>
<tr>
<td>Polystyrene (EPS, XPS)</td>
<td></td>
</tr>
<tr>
<td>Polyurethane (PUR)</td>
<td></td>
</tr>
<tr>
<td>Nanostructured silicas, aerogels</td>
<td></td>
</tr>
<tr>
<td>Evacuated insulations (VIP)</td>
<td></td>
</tr>
</tbody>
</table>

- bandwidth
- best type
### Features of Synthetic Insulation Materials

<table>
<thead>
<tr>
<th>Insulation Material</th>
<th>Thermal conductivity W / (m·K)</th>
<th>Density Kg / m³</th>
<th>Material class</th>
<th>Capillary Activity*</th>
<th>Dehumidification*</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock wool, Glass wool</td>
<td>0.035 - 0.040</td>
<td>20-200</td>
<td>A1-B2</td>
<td>no</td>
<td>-</td>
<td>roof, ceiling, wall, floor</td>
</tr>
<tr>
<td>Mineral foam</td>
<td>0.045</td>
<td>115</td>
<td>A2</td>
<td>no</td>
<td>hydrophobic treated</td>
<td>wall</td>
</tr>
<tr>
<td>Polystyrene (expanded) EPS, Graphite modified</td>
<td>0.035-0.040, 0.032</td>
<td>10-60</td>
<td>B1</td>
<td>no</td>
<td>- (cleft cellular)</td>
<td>roof, ceiling, wall, floor</td>
</tr>
<tr>
<td>Polystyrene (extruded)</td>
<td>0.035-0.040</td>
<td>20-60</td>
<td>B1</td>
<td>no</td>
<td>- (cleft cellular)</td>
<td>flat roof, ceiling, cellar</td>
</tr>
<tr>
<td>Polyurethane (PUR)</td>
<td>0.025-0.040</td>
<td>15-80</td>
<td>B1/ B2 (foil clad)</td>
<td>no</td>
<td>- (cleft cellular)</td>
<td>flat roof, ceiling, cellar</td>
</tr>
<tr>
<td>Nano-structured silicas, aerogels</td>
<td>0.015-0.025</td>
<td>150-300</td>
<td>A1</td>
<td></td>
<td></td>
<td>core material for VIPs</td>
</tr>
<tr>
<td>Evacuated Insulations Vacuum Insulation Panels (VIPS)</td>
<td>(0.002), 0.008</td>
<td>150-300</td>
<td>A2-B1</td>
<td>no</td>
<td>-</td>
<td>roof, ceiling, wall, floor</td>
</tr>
</tbody>
</table>

* see text

### Features of Natural Insulation Materials

<table>
<thead>
<tr>
<th>Insulation Material</th>
<th>Thermal conductivity W / (m·K)</th>
<th>Density Kg / m³</th>
<th>Material class</th>
<th>Capillary Activity*</th>
<th>Dehumidification*</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose (fluffs) (slabs)</td>
<td>0.040-0.045</td>
<td>30-80 (F)</td>
<td>B2</td>
<td>+</td>
<td></td>
<td>roof, ceiling, wall, floor</td>
</tr>
<tr>
<td>Cork (expanded shred) (slabs)</td>
<td>0.040-0.045 (shr)</td>
<td>75-85 (shr)</td>
<td>B2</td>
<td></td>
<td></td>
<td>excavation fill*, rf, cl, wl, fl (S)</td>
</tr>
<tr>
<td>Wood fibre (loose) (slabs)</td>
<td>0.040-0.052 (L)</td>
<td>30-40 (L)</td>
<td>B2</td>
<td>++ (S)</td>
<td></td>
<td>rf, cl, wl, fl</td>
</tr>
<tr>
<td>Wood wool (mineral bound slabs)</td>
<td>0.065-0.090</td>
<td>330-500</td>
<td>B1</td>
<td></td>
<td></td>
<td>only for boarding; plaster base</td>
</tr>
<tr>
<td>Coco fibre</td>
<td>0.045</td>
<td>70-80</td>
<td>B2</td>
<td>yes</td>
<td>++</td>
<td>floor, stuff wool</td>
</tr>
<tr>
<td>Flax</td>
<td>0.040</td>
<td>C.a. 30</td>
<td>B2</td>
<td>++</td>
<td></td>
<td>rf, cl, wl, fl</td>
</tr>
<tr>
<td>Hemp (loose, mat)</td>
<td>0.050-0.055 (L)</td>
<td>40-60 (L)</td>
<td>B2</td>
<td>++</td>
<td></td>
<td>rf, cl, wl, fl</td>
</tr>
<tr>
<td>Perlite (fill) (slabs)</td>
<td>0.050-0.055 (F), 0.055-0.060 (S)</td>
<td>10...165</td>
<td>B2 (F)</td>
<td>A2/B1/ B2 (S)</td>
<td></td>
<td>excavation fill*, flat roof (S)</td>
</tr>
</tbody>
</table>

* see text
only approved as a whole system from one manufacturer

plaster up all around each insulation slab on the back to avoid rear-ventilation with cold air

no plaster on butt joints

place insulation carefully without gaps

fill voids only with insulation material (not with plaster or mortar)

anchorage of external elements (railings, porches etc.): uncouple thermically with mounting-elements (PUR) or impregnated gluelam

Uncouple anchoring of underconstruction thermically from wall (especially in case of aluminium-structures)

consider underconstruction in fire protection

place insulation carefully without gaps (if recommended: slightly oversized)

fill voids only with insulation material

many insulation materials require a wind seal outside

vapour-sealed facades require a rear-ventilation
Comparison of both Insulation Systems

<table>
<thead>
<tr>
<th>Bonded Thermal-Insulation System</th>
<th>(rear ventilated) Curtain Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>high insulation-values easy to reach (single-layer up to approx. 30 cm insulation thickness)</td>
<td>insulation effect reduced up to 20%, due to thermal bridges of the necessary anchors? special solutions required</td>
</tr>
<tr>
<td>over 34 years of proved durability</td>
<td>recycling mostly by simple disassembling</td>
</tr>
<tr>
<td>recycling with passable effort</td>
<td>higher fire protection needs grantable with class-A-materials (e.g. lintels, high-rise buildings)</td>
</tr>
<tr>
<td>wide range of different applicable materials</td>
<td>higher construction costs</td>
</tr>
<tr>
<td>higher fire protection needs grantable with class-A-materials (e.g. lintels, high-rise buildings)</td>
<td>very low maintenance (depending on covering material)</td>
</tr>
<tr>
<td>very low costs in use of EPS-slabs</td>
<td>noticeable improvement of noise control feasible</td>
</tr>
<tr>
<td>improved noise control also feasible with EPS by modified slab-materials</td>
<td></td>
</tr>
</tbody>
</table>

Arguments for High-Insulated-Constructions

- share of costs for insulation-material is very low (ca. 1/3 of total amount)
- cost-optimised insulation-thickness rises with the energy-prices
- later added insulation is in any case uneconomical
- thermal-bridge optimised constructing is easier with high insulation-thickness
- secure prevention of mildew also at intensive habitation and in critical areas (e.g. corners behind gardrobes)
- docile (or ‘well tempered’) cooling-down of the building in case of longer heating-omission (category temperature 18…19°C)
  - social housing – assured for a good future – also in case of extreme (?) energy scenarios
  - ‘warmth-guarantee’ as marketing-advantage
- optimal thermal behaviour also in summer
## Insulation Materials: Amortisation of Fabrication Energy

<table>
<thead>
<tr>
<th>Insulation Material</th>
<th>Thermal Conductivity [W/(m·K)]</th>
<th>Density [kg/m³]</th>
<th>Thickness for U=0.15 W/(m²K) [cm]</th>
<th>Fabrication Energy [kWh/m³ Insulation Material]</th>
<th>Fabrication Energy [kWh/m² external wall]</th>
<th>Amortisation Time [months]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanded Polystyrene (EPS)</td>
<td>0.035...0.040</td>
<td>15</td>
<td>21...24</td>
<td>600</td>
<td>130...145</td>
<td>13...15</td>
</tr>
<tr>
<td>EPS, graphite modified</td>
<td>0.032...0.035</td>
<td>15...17</td>
<td>19...21</td>
<td>600...680</td>
<td>115...145</td>
<td>11...14</td>
</tr>
<tr>
<td>Glass wool</td>
<td>0.035...0.040</td>
<td>120</td>
<td>21...24</td>
<td>700...1200</td>
<td>145...290</td>
<td>14...29</td>
</tr>
<tr>
<td>Rockwool</td>
<td>0.035...0.040</td>
<td>150</td>
<td>21...24</td>
<td>530...680</td>
<td>110...140</td>
<td>11...14</td>
</tr>
<tr>
<td>Mineral foam</td>
<td>0.045</td>
<td>115</td>
<td>27</td>
<td>250</td>
<td>70</td>
<td>7</td>
</tr>
<tr>
<td>Wood fibre (slabs)</td>
<td>0.040...0.045</td>
<td>180</td>
<td>24...27</td>
<td>600...1400</td>
<td>145...380</td>
<td>14...37</td>
</tr>
<tr>
<td>Cork (slabs)</td>
<td>0.040...0.045</td>
<td>120</td>
<td>24...27</td>
<td>65...450</td>
<td>20...120</td>
<td>2...12</td>
</tr>
<tr>
<td>Glass wool</td>
<td>0.035...0.040</td>
<td>40</td>
<td>24...27</td>
<td>250...400</td>
<td>60...110</td>
<td>6...11</td>
</tr>
<tr>
<td>Rockwool</td>
<td>0.035...0.040</td>
<td>60</td>
<td>24...27</td>
<td>210...270</td>
<td>50...75</td>
<td>5...7</td>
</tr>
<tr>
<td>Cellulose fluffs</td>
<td>0.04</td>
<td>40...60</td>
<td>27</td>
<td>45...70</td>
<td>15...20</td>
<td>2...3</td>
</tr>
<tr>
<td>Wood fibre (loose)</td>
<td>0.04</td>
<td>100</td>
<td>27</td>
<td>300...700</td>
<td>80...190</td>
<td>8...18</td>
</tr>
<tr>
<td>Flax</td>
<td>0.04</td>
<td>30</td>
<td>27</td>
<td>20...40</td>
<td>5...10</td>
<td>1...2</td>
</tr>
<tr>
<td>Hemp (mat)</td>
<td>0.040...0.050</td>
<td>40</td>
<td>27...33</td>
<td>50...80</td>
<td>15...25</td>
<td>2...3</td>
</tr>
</tbody>
</table>

## Bonded Thermal-Insulation-Systems: Ecological Effects and Costs

![Graph showing ecological indicators and costs for different materials](image)
VIP – Vacuum Isolation Panels and Elements

VIP-Elements = Panel + Protective Layers
- EPS-layers (Bonded Thermal Insulation System)
- PUR-layers

VIP-Panels:
- core: pyrogenic silica
- protective membran
- envelope: vacuum sealed (impervious to diffusion)
- sensor-disc for vacuum-check

VIP-Elements = Panel + Protective Layers

Transparent Insulation (TI): Function and Designs

Passive-Solar Accumulating Wall
- incidence angle in winter
- incidence angle in summer

Transparent BTIS
1. absorber coating
2. TI-capillary panel
3. armouring
4. translucent glass-mortar

TI-Facademodule
1. glass cover
2. absorbing layer
3. closable air inlet
4. and outlet (summer)
Transparent Insulation (TI): Application Area and Benefits

- walls of density $\geq 1200$ kg/m$^3$
- walls without any existing insulation
- surface share of TI $\geq 5 \ldots 10\%$
- energy benefits / opaque thermal insulation: $80 \ldots 130$ kWh/m$^2$a
  (south surface; $U_{\text{opaque}} = 0.15$ W/m$^2$K)
- higher share of TI:
  - decreasing specific energy benefit
  - risk of overheating in summer
- costs 5 times higher than opaque BTIS
- TI do not replace high efficient thermal insulation, only considered as complement

Thermal Bridges: Characterisation

- thermal bridges = areas with higher heat drain than in standard component
- cooling-down of inner surface
- below critical value: interior air humidity condenses in place
- humid, cool surface $\rightarrow$ mildew
- consequences:
  - needless higher energy-losses
  - risk of component-damages caused by condensate
  - risk of health-damages caused by mildew
  - receivables of tenants; vacancy
- remedy: thermal protection raises inner surface temperature
Thermal Bridges: Examples

External Corner (‘Geometrical Thermal Bridge’)
- outer surface > inner surface
- ? higher heat-flux than in centre of wall area (standard surface)

Concrete Ceiling (‘Material Thermal Bridge’)
- component with high(er) thermal conductivity pierces standard surface or insulation
- e. g. thermal conductivity concrete ceiling > brickwork
- ? higher heat-flux than in centre of wall area (standard surface)

Thermal Bridges: Planning

Thermal-Bridge free Building begins in Planning Office
- insulating mantle has to wrap up the heated room without interruption
- refurbishment: some thermal bridges only reduced (e. g. basement ceiling at cellar walls)
- comparison of different solutions: estimation of efficiency aided by software
  - catalogues of thermal bridges
  - calculation tools
- important: detail drawings of critical areas
- no craftsman can compensate a lacking concept!

Avoiding new Thermal Bridges: Plinth

- standard closing-off profile made of aluminium (thermal conductivity 4000 times higher than insulation material)
- ? thermal bridge
- higher heat losses equivalent to 1…2 m² insulated outwall area per meter profile
- thermotechnical interpretation: ‘ground floor 1…2 m higher due to aluminium profile’
- thermal uncoupled closing-off system avoids higher heat losses and low temperatures on inner surface

Airtightness: Reasons for Airtight Buildings

- gap, 1mm width x 1m length (related to 1m²); airstream pervades construction
- U-value declined by factor 5!
  $(0.3 \div 1.44 \text{ W/m}^2\text{K})$
- airstream carries interior air humidity into construction; amount of condensate due to convection more than 100 times higher than by vapour-diffusion!
- consequences:
  - insulation largely ineffective
  - risk of grave construction damages
  - dissatisfaction of dwellers because of infiltration
  - abatement of rent, vacancy
- ventilation system with heat recovery requires airtight building-envelope
Airtightness: Respiration-Air via Leakages?

- yield of airflow through leakages insufficient
- air quantity fluctuates with weather (insufficiency ... infiltration, cold draughts), do not meet the needs
- respiration air via leakages = unhygienic
- superior: - planned outer-air apertures
  - ventilation system

Planning Airtightness: Concept of Airtightness

**Determine Airtight Envelope**

- course: - flat towards outer air
  - in-between flats (e. g. at installation ducts)
  - airtight separation from cellar (housed staircase)
- layer: determine position of airtight layer for every component part
  - sealing of plain (e. g. inside plaster at brickwork)
  - connection in line between different partial areas
  - punctiform connections at pervasions for construction and building services
  - components with splices for mounting and closing (windows, doors,..)
- prevent pervasions and connections (e. g. building services ? installation layer)
- prevent change of airtight-layer (inside? outside; e. g. insulation upside rafters)
- planning details (connection details)
Exemplary Solutions: Window-Mounting

- Mount window from outside the exterior wall (fixing e.g. by elbow-mounting)
- Airtight connection of window frame to airtight-layer of exterior wall
  - Fleece cladded tape on prepared subsurface
  - Later inserted with BTIS-glue
- Insulation of blind frame as far as possible
- Cant insulation for wider angle of view and improved incident light

Exemplary Solutions: Plinth and Basement

- Insulation of basement due to cost reasons only 25 cm below terrain
- Supplemented with frost apron
- Remaining Effect of Thermal Bridge:
  + 0.86 m² outwall area per plinth meter
- Improvement: basement insulation down to 50 cm below terrain;
  + Frost apron at 25 cm below terrain
- Additional insulation stripe at basement walls towards basement ceiling (at inner walls too)
Exemplary Solutions: Attics or Sills

- Uninsulated
- High Efficient Ins.
- + Wrapped Slab
- coupled

++3.5 m²
mildew !
++0.50 m²
++0.15 m²
++0.02 m²

Thermal Bridge Losses = Additive Outwall Area / m Balcony Connection

Exemplary Solutions: Projecting Ferroconcrete Balcony Slab

- Uninsulated
- High Efficient Ins.
- + Wrapped Slab
- coupled

++3.5 m²
mildew !
++0.50 m²
++0.15 m²
++0.02 m²

Thermal Bridge Losses = Additive Outwall Area / m Balcony Connection
Quality Assurance

Aim: Reaching the Targeted Energy-Standard

- draft-planning time: concepts of insulation and airtightness
- execution-planning: graphics of connection details
  (minding the practicability at the construction site)
- tender and allocation/contracting: pointing to particularities in execution
- defining interfaces to other crafts and performances
- specify the particular quality criteria of the construction parts
- introducing craftsmen early while executing + monitoring the construction
- coordinate the responsibilities and competences of the crafts
- adjust immediately mounting faults or wrong decisions at material choice
- result checking by means of Blower-Door + Thermography
- use check lists

Exempla section, 3 slides
Main issues and definitions

- Well-insulated houses have reduced energy need but still require electricity for lights, fans and other equipment.
- Photovoltaic systems (PV) generate electricity from solar radiation, a renewable energy source, at the point of use.
- As the cost of fossil fuels steadily increases, PV becomes also economically attractive.
- Electricity produced by PV can be used on the spot, stored in batteries, or sold to the electricity distribution network.
- Mature technology with increasing demand worldwide.
- No noise, no moving parts, no emissions on-site.

Main recommendations

- PV replacing a traditional building element, e.g. roof or facade cladding, reduces investment cost & provides « free » electricity.
- Wide range of off-the-shelf PV products in various shapes, colours, costs and efficiencies to match the building project.
- Design guidelines for PV system:
  - Access to solar radiation: horizontal orientation within due South +/- 45°, vertical tilt within 90° minus site latitude +/- 45°.
  - Access to building surfaces on which to install PV: roof, facade, balconies, glazing, solar shading, ...
  - Avoid shading by surrounding vegetation or buildings.
  - Sizing of PV according to electricity needs.
  - Electricity storage by means of battery arrays or electricity distribution network.
Example: The Yellow House (Aalborg, DK)

- 4 storeys, 8 apartments
- Built in 1900, renovated in 1996, with focus on solar energy
- 22,3 m² of PV panels:
  - Some tilted vertically for optimal integration with building facade
  - Some with 30° tilt off vertical axis for maximised solar incidence
- Electricity production:
  - ~ 30 kWh / m² per year
  - ~ 25% of the electricity sold to the electricity distribution network


Energy certificate in France

- Annual primary energy consumption in kWh/m²
- Use of energy bill if collective heating, otherwise calculation for each unit, either simplified (3CL) or simulation (COMFIE)
- Annual CO₂ emissions in kg CO₂ / m²
- Annual energy cost in € / m²
- A to G equivalence, see graph
- Recommendations
**Energy certificate in Germany**

**Energy pass for new, refurbished, saled or rented buildings**

- **Calculated energy requirement** \([\text{kWh/(m}^2\text{a})]\):
  - end energy for heating, DHW, ventilation, cooling
  - primary energy (« total energy efficiency »)
  - energy quality of building envelope \((H_\text{r} = U_{\text{building}})\)
  - optional: CO₂ emissions \([\text{kg/(m}^2\text{a})]\)

- **Actual energy consumption** \([\text{kWh/(m}^2\text{a})]\):
  (buildings with > 4 flats, energy standard 1977-94)
  - use of energy bill (min. 3 years)
  - adjusted degree days
  - end energy for heating, DHW

Reference values for end energy - Recommendations

**Energy certificate in Hungary**

- **Annual primary energy consumption in kWh/m²**
- **Certification is based on calculations, 3 possibilities**: simplified calculation, detailed calculation, dynamic simulation
- **CO₂ emissions** and energy costs not included
- **I to A+ equivalence**, see graph
- **Recommendations**
Energy certificate in the Netherlands

- **Annual energy use (MJ/m²)**
  - expressed in Energy Index A++ to G

- **Certification is based on calculation (EPA-U, excel)**

- **Input calculation:**
  - Building specifications
  - Installations (HVAC)

- **Recommendations**
  - Energy saving measures

---

Energy certificate in Norway (proposal)

- **Documentation**
  - Area, Year of construction, refurbishment etc.

- **Rating based on annual delivered energy [kWh/m²a] (calculated)**
  - Calculation: Simplified, detailed, dynamic
  - Actual energy consumption (if available)
  - Reference values for delivered energy

- **Recommendations**
Energy certificate in Sweden

- Sum of measured delivered annual energy in kWh/m² (excl. electricity use by tenants)
- Measured delivered electricity use in kWh/m² stated separately
- Obligatory Ventilation Control (OVK) – Yes/No
- Voluntary radon gas measurement(s) – Yes/No
- Recommendations cost-effective energy measures
- Misc. building info