Comparative Life-Cycle Analysis of Building Materials for the Thermal Upgrade of an Existing Building

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Background

- The ‘Europe 2020 Strategy’ sets a 20% energy saving target by 2020.
- The Directive 2018/844/EU requires minimum energy performance for both new and renovated buildings.
- The passive house concept is a model for high performance buildings.
- In Sweden, 30% of the building stock was built between 1961 and 1975.

Number of dwellings by type of building and period of construction (source: Statistics Sweden).
Research questions

1. What are the energy and carbon implications of retrofitting a building?

2. What if we assume different passive house standards?

3. What if we the primary energy use for retrofitting a building compared to the operational energy saving?

4. What if we assume alternative building materials?
Research structure and methods

- Identification of the case-study building
- Definition of passive house standard
- Design of alternative retrofitted buildings
- Dynamic energy modelling
- Life cycle primary energy and carbon analysis
- Interpretation of the results
Case study

- **Location**: Ronneby, Southern Sweden
- **Year of construction**: 1974
- **Building type**: concrete-framed building
- **Total heated floor area**: 2000 m²
- **Ventilation system**: mechanical ventilation for exhaust air
- **Heat energy supply**: district heating system
**Definition of passive house standard**

We selected two different passive house standards applicable in Sweden:

- 50 kWh/m², year (50PH)
- 30 kWh/m², year (30PH)

to be achieved in the retrofitted buildings.

<table>
<thead>
<tr>
<th>Passive house standard</th>
<th>Energy use* [kWh/m², year]</th>
</tr>
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<tbody>
<tr>
<td>FEBY12</td>
<td>≤ 50</td>
</tr>
<tr>
<td>Passive House Institute (PHI)</td>
<td>≤ 30</td>
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</table>

* space and tap water heating
Design of the retrofitted buildings

The following retrofitting measures are adopted:

**efficiency upgrade of technical devices**
- energy-efficient ventilation fans
- energy-efficient ventilation heat recovery (VHR) unit
- efficient water taps

**thermal improvement of the building envelope**
- extra insulation
- improved airtightness

in the following building parts:
- basement
- attic
- windows and, if needed, external walls
Life Cycle Analysis

PRODUCTION PHASE
- Manufacturing of materials
- Energy recovery from biomass residues

CONSTRUCTION PHASE
- Transport of materials to the building site
- On-site construction work

OPERATION PHASE
- Space and tap water heating
- Electricity for ventilation

MAINTENANCE PHASE
- Manufacturing of materials
- Energy recovery from biomass residues

END-OF LIFE PHASE
- Demolition and sorting
- Transport of materials
- Energy recovery/recycling of waste

Energy supply system

Carbon emissions or displacement
Comparing alternative building materials

We combine alternative building materials for:

**thermal insulation**
- glass wool (G)
- rock wool (R)
- wood fibre (W)

**building cladding**
- aluminium cladding (A)
- clay tiles cladding (B)
- wood cladding (W)

**windows**
- aluminium-framed windows (A)
- wood-framed windows (W)

Number of alternatives: 6 for 50PH and 18 for 30PH.
Results of the 50PH retrofitted buildings

50PH retrofitted buildings

- Glass wool
  - Alum.
  - Wood

- Rock wool
  - Alum.
  - Wood

- Wood fibre
  - Alum.
  - Wood

Chart showing:
- Total PE
- Total CO2

MWh vs CO2

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 642384.
Results of the 50PH retrofitted buildings

50PH retrofitted buildings

Glass wool

Rock wool

Wood fibre

INSULATION

HIGH-ENERGY OPTION

Alum. Wood Alum. Wood Alum. Wood

Total PE Total CO2

MWh
Results of the 50PH retrofitted buildings

50PH retrofitted buildings

Glass wool
Rock wool
Wood fibre

Alum. Wood Alum. Wood Alum. Wood

LOW-ENERGY OPTION

MWh
1500 1000 500 0
Total PE

Total CO2

m CO2
1500 1000 500 0

INSULATION

WINDOW FRAME

TOTAL PE

TOTAL CO2
Results of the 30PH retrofitted buildings

30PH retrofitted buildings

- Glass wool
  - Wood
  - Brick
  - Alum

- Rock wool
  - Wood
  - Brick
  - Alum

- Wood fibre
  - Wood
  - Brick
  - Alum

INTEGRATION:

- INSULATION
- CLADDING
- WINDOW FRAME

A = aluminium
W = wood

Graph showing MWh vs. tCO2 for different materials and configurations.
Results of the 30PH retrofitted buildings

- **Building Materials**
  - **Insulation**:
    - Glass wool
    - Rock wool
    - Wood fibre
  - **Cladding**:
    - Wood
    - Brick
    - Aluminium
  - **Window Frame**:
    - Wood
    - Brick
    - Aluminium

- **Energy Consumption**
  - **Total PE**
  - **Total CO2**

- **High-Energy Option**

**Note:**
- A = Aluminium
- W = Wood

**Source:**
- Funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642384.
Results of the 30PH retrofitted buildings

- Glass wool
- Rock wool
- Wood fibre

WOOD FRAME
- A = aluminium
- W = wood

INSULATION

LOW-ENERGY OPTIONS

MWh

Total PE  Total CO2

0  500  1000  1500  2000  2500  3000  3500  4000

tCO2

0  500  1000  1500  2000  2500  3000  3500  4000
Answering to research questions

1. **What are the energy and carbon implications of retrofitting a building?**
   Additional primary energy use and carbon emissions, depending on the passive house target and on the use of building materials.

2. **What if we assume different passive house standard?**
   The 30PH buildings results in X6 primary energy and X11 carbon emissions compared to the 50PH buildings, due to additional retrofitting measures.
3. How much is the primary energy use for retrofitting a building compared to the operational energy saving?

The primary energy used to retrofit the 50PH and 30PH buildings accounts for 10% and 25%, on average, of the operation primary energy saving.
50PH retrofitted buildings

**PRIMARY ENERGY**

- **G**=glass wool; **R**=rock wool; **W**=wood fibre/wood; **A**=aluminium

**CARBON EMISSIONS**
50PH retrofitted buildings

**PRIMARY ENERGY**

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**CARBON EMISSIONS**

**WOOD FIBRE INSULATION, ALUMINIUM-/WOOD-FRAMED WINDOWS**

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G=glass wool; R=rock wool; W=wood fibre/wood; A=aluminium
30PH retrofitted buildings

**PRIMARY ENERGY**

- **G**=glass wool; **R**=rock wool; **W**=wood fibre/wood; **A**=aluminium; **B**=brick
30PH retrofitted buildings

PRIMARY ENERGY

G=glass wool; R=rock wool; W=wood fibre/wood; A=aluminium; B=brick
30PH retrofitted buildings

G=glass wool; R=rock wool; W=wood fibre/wood; A=aluminium; B=brick

GGA, GGA, GGGB, GGWA, RRWA, RRWW, RRBA, RRBW, RRAA, RRAW, WWWA, WWWW, WWBA, WBBW, WWA, WWAA, WWAW

Production  Construction  Maintenance  End-of-life  Total

GGA, GGA, GGGB, GGWA, RRWA, RRWW, RRBA, RRBW, RRAA, RRAW, WWWA, WWWW, WWBA, WBBW, WWA, WWAA, WWAW

G=glass wool; R=rock wool; W=wood fibre/wood; A=aluminium; B=brick

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30PH retrofitted buildings

CARBON EMISSIONS

G=glass wool; R=rock wool; W=wood fibre/wood; A=aluminium; B=brick
Answering to research questions

4. What if we assume alternative building materials?
The choice of building materials is relevant. Maximizing the use of brick and wood can save up to 38% of energy and up to 42% of carbon emissions.
Conclusions

- Design strategies should pay attention to the durability of building materials to reduce the maintenance need.
- Design for disassembly could facilitate the disassembly of building parts in future, optimizing the efficiency of CDW recovery.
- Further studies on cost-effectiveness of the retrofitting measures should be investigated more deeply.
Thank you for your attention

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