Life cycle façade refurbishment for post-war residential buildings

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MSc Graduation, Building Technology

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External Examiner: R. Binnekamp
Contents

- Introduction
- Literature research
- Design approach
- Case study analysis
- Building services
- Façade
- Design
- Conclusions, recommendations & future research
Introduction – Problem statement

Problem Statement

- *Global warming* by GHG by fossil-fuels
- 90+% still fossil fuels used
- Depletion of these *fossil fuels*
- *Energy demand* needs to be *lowered*

Residential buildings

- 40% of the GHG by buildings
- 28.8% of energy use is by households
- 50% of Dutch buildings built before 1970, large part not insulated well
- Energy use of buildings lowered by refurbishment, savings possible of 75% (energy label G to A).

Energy consumption in Germany in 2005
*Source: Hegger et al. (2008)*
Introduction – Life cycle energy

Life cycle energy (Joule)
- Embodied energy
  - Initial embodied energy (extraction, processing, manufacturing, transportation, assembly)
  - Recurring embodied energy (refurbish and maintenance)
- Operation energy
- Demolition energy

Embodied energy in buildings (Joule)
- 10-40% of total Energy
- 40% reduction possible with reused and recycled materials

Environmental impact (euro)
- Also includes global warming potential, ozone depletion potential etc.
- Can be expressed in environmental costs

Source: Crowther (1999)
Introduction – Goal

Goal

- Develop a design approach for residential buildings, to improve the Life cycle energy (operation + embodied) and environmental impact

- Give recommendations for other designers concerning materials for refurbishment

- Show possibilities for future research
Main research question

How can the façade of a post-war residential building be refurbished, to make the **operation energy and embodied energy (life cycle energy) as low as possible**, while also considering other factors that influence the environmental impact?
Introduction – Research questions

Sub research questions

**Refurbishment**  
1. What measures can be taken to improve the façade of a (residential) building with refurbishment?

**Energy performance**  
2. How can the façade be upgraded to increase the energy performance of a (residential) building?

**Case study building**  
3. What type of building can best be used for the case study design?

**Design approach**  
4. What approach can be used to lower the energy use and environmental impact in façade refurbishment of a residential building, (and how can this be implemented onto the case study)?

**Materials**  
5. What materials can best be used in the façade (for refurbishment) to lower the environmental impact, with a focus on the embodied energy?

**Reuse/recycling**  
6. How can reusing and recycling of (façade) materials contribute to lower the environmental impact, with a focus on the embodied energy?
Introduction – Boundary conditions

Tools

-Operation energy: EPC, Enorm
-Embodied energy: NIBE database, Excel
-Environmental costs: NIBE database, Excel
-Building costs: NIBE database, Excel, internet

Research focus

-Refurbishment of residential buildings
-Design for one case study, focus on façade
-Assessment of energy performance, material properties, environment
Introduction – Research structure

Structure of research thesis

1. Introduction of research & graduation plan

2.1 Refurbishment
2.2 Energy performance
2.3 Example studies

2.4 Materials
Example studies and/or other case studies

2.5 Reuse and recycling
Example studies and/or other case studies

3. Design approach

4. Case study analysis

5. Material comparison

6. Strategy comparison

7. Case study design

8. Conclusions Recommendations Evaluation

Introduction – Literature research – Design approach – Case study analysis – Building services – Façade analysis – Design – Conclusions
Sub research question

1. What measures can be taken to improve the façade of a (residential) building with refurbishment?
Literature research - Refurbishment

Definitions

In refurbishment not only the defective building components are repaired or replaced, but also the outdated components or surfaces.

Upgrading in fire protection, acoustics and thermal performance.

```
Large intervention

Demolition
Reconstruction
Conversion
Total refurbishment

Small intervention

Refurbishment
Partial refurbishment
Repairs/maintenance
Renovation/maintenance

Completely demolish/rebuild
Affect structure of the building
Stipped to load-bearing frame
Fire protection, acoustic upgrading and thermal performance
Replace/repair outdated components/surfaces
Place/repair defective parts
Cosmetic repairs
```
Literature research - Refurbishment

Strategies

- Façade replacement
- Exterior addition
- Exterior upgrade
- Interior addition
- Interior upgrade
Literature research – Energy

Sub research question

2. How can the façade be upgraded to increase the energy performance of a (residential) building?

- Improving insulation
- Ventilation
- Domestic hot water/heating system
- Existing components and new sustainable materials
- Avoid overheating
- Daylighting, efficient lighting and control systems
- Efficient appliances and controls
Sub research question

3. What **type of building** can best be used for the **case study design**?

- Building period analysis
- Building type analysis
- Energy performance for different building types and periods
- Environmental costs per building type (Greencalc+)
- Example studies
Conclusions

- Building period 1945-1975
- Portiek flat
- More types of façade materials/construction types
Conclusions

- Building period 1945-1975
- Portiek flat
- More types of façade materials/construction types

Marco Pololaan, Kanaleneiland, Utrecht

- Residential building from 1960’s
- Portiek flat
- Different façade materials
- Bad energy performance (Label F/G)
- Renovation of 4 flats by **Portaal**
- Lifespan of 35 years after renovation
Design approach

Sub research question

4. What approach can be used to lower the energy use and environmental impact in façade refurbishment of a residential building, (and how can this be implemented onto the case study)?
Design approach

Approach

1. CASE STUDY
Case study analysis
Current situation & plans of Portaal:
- Context
- Building space
- Load-bearing structure
- Materials
- Building services
- Energy use currently (EPC)
- Indoor comfort & damages

2. BUILDING SERVICES
Aspects
1. Ventilation
2. Heating
3. Cooling
4. Lighting
5. Electricity

Literature study
Different possibilities, concepts and strategies

EPC calculation
Energy use, in old façade situation, per installation possibility

Conclusion: final choice
Final building services strategy, used in all façade strategy possibilities

3. FAÇADE
Strategies
1. Exterior addition
2. Façade replacement
3. Interior insulated layer
4. Partial replacement, partial addition (Portaal)

EPC software
What is the EPC with the desired R-values & chosen installations

Comparison materials:
- Embodied energy
- Building costs
- Environmental costs

Excel file
Best choice for strategies

Strategy analysis
Calculation strategies

EPC software
Operation energy
- EPC

Excel
Embodied energy
Building costs
Environmental costs

Conclusion
Comparison strategies for all different aspects

Material comparison
Per Component: What R-value is needed per component?
What is the building lifespan?
What material is best for this component?

Strategy comparison
Comparison 4 Different Strategies:
Total Energy Use [MJ] = Embodied Energy + Operation Energy
Total Building Costs [€]
Total Environmental Costs [€]

4. DESIGN
Variation studies
- Building plans
- Glass percentage
- Glass type
- Thermal mass
- Infiltration
- New/old balconies
- Balance between inside space and new balconies

Final Design
Use conclusions to make a design, from:
- Case study analysis
- Building services strategies
- Façade strategies
- Variation studies

Comparison designs:
- Current situation
- Own design
- Portaal's design

Assessment in:
- Embodied Energy
- Operation Energy
- Environmental Costs
- Building costs

Recommendation for final design for the building for Portaal, and for other buildings and designers
Design approach

Simplified approach

1. **CASE STUDY ANALYSIS**
   - Current situation
   - Plan portal

2. **BUILDING SERVICES**
   - Literature study
   - EPC calculations
   - Strategy choice

3. **FAÇADE**
   - Material comparison
   - Strategy comparison

4. **DESIGN**
   - Variation studies
   - New design
   - Comparison to old & Portaal
Case study analysis

Building space

[Diagram showing building space with different types: Type A, Type B, Type C, Type D.]

[Introduction – Literature research – Design approach – Case study analysis – Building services – Facade analysis – Design – Conclusions]
Case study analysis

Load-bearing structure

Materials

- South and North: Masonry
- Prefab concrete elements
- Plates in wooden frames
- Single glazing
Case study analysis

**Building Services**
- District heating
- Electric boiler for warm water
- Radiators
- Natural ventilation

Plan Portaal: add mechanical exhaust

**Energy Index**
- Label F to G
- Top right apartment has highest Index EI = 3.28

**EPC**
- EPC = 2.99
- Operation Energy/ year = 138,000 MJ
- Heating/year = 99,200 MJ

**Indoor comfort**
- Cold draught due to single glass and ventilation
- Acoustics from inside and outside

**Improvement insulation**
If insulation is improved to

\[ R_c = 3.5 \text{m}^2\text{K}/\text{W} \rightarrow EPC = 1.59 \]
## Building Services - Analysis

### Ventilation

<table>
<thead>
<tr>
<th>Sub type</th>
<th>Comfort</th>
<th>Sound</th>
<th>Space use</th>
<th>Costs</th>
<th>Energy use system</th>
<th>Heat savings</th>
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<td>++</td>
<td>++</td>
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<td>++</td>
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<tr>
<td>Mech. Supply</td>
<td>+/-</td>
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<tr>
<td>Mechanical</td>
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<tr>
<td>Local unit</td>
<td>++</td>
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<td>+/-</td>
<td>-</td>
<td>+/-</td>
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### Heating

<table>
<thead>
<tr>
<th>Sub type</th>
<th>Availability &amp; Costs</th>
<th>Suitability with ventilation &amp; heat output system</th>
<th>EPC reduction compared to old situation, district heating</th>
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<tr>
<td><strong>Fossil fuels</strong></td>
<td></td>
<td></td>
<td>Low T</td>
</tr>
<tr>
<td>CV heating</td>
<td>+</td>
<td>+</td>
<td>+/-</td>
</tr>
<tr>
<td><strong>Electric heating</strong></td>
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<tr>
<td>CV heating</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><strong>Biomass</strong></td>
<td></td>
<td></td>
<td>+/-</td>
</tr>
<tr>
<td>Wood/Biomass</td>
<td>+/-</td>
<td>+</td>
<td>+/-</td>
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<td><strong>Solar heat collectors</strong></td>
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<tr>
<td>Unglazed</td>
<td>-</td>
<td>+</td>
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<tr>
<td>Flat-plate</td>
<td>-</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Air collector</td>
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<td>+</td>
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<tr>
<td>Vacuum-tube</td>
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<td><strong>Combined Heat &amp; Power</strong></td>
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<tr>
<td>Micro CHP</td>
<td>-</td>
<td>+</td>
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<td>District heating</td>
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<td>+/-</td>
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<td><strong>Heat pump</strong></td>
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<td>Shallow soil</td>
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<tr>
<td>Deep ground</td>
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<td>Ground/surface water</td>
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<td>+/-</td>
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<td>Long-term</td>
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</table>
Conclusions Building Services

- **Heat pump** with **groundwater storage** for heating (low temperature)
- **District heating** (already present) for domestic hot water
- **Local units** underneath windows, with CO2 sensors and **heat recovery** for ventilation
- EPC improved from 1.59 → 0.76
Façade analysis - Approach

Façade design approach

Introduction – Literature research – Design approach – Case study analysis – Building services – Façade analysis – Design – Conclusions
## Façade analysis - Materials

### Façade design approach – Material database

#### Material Database

- Choice best materials
- Construction layers
- Façade strategy design
- Excel calculations

#### Output

- RC-values
- Embodied Energy
- Environmental Costs
- Building costs
- Operation Energy

#### Introduction

- Literature research

#### Design approach

- Case study analysis
- Building services

#### Building Design

- Façade analysis
- Design
- Conclusions

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<table>
<thead>
<tr>
<th>CAVITY INSULATION (m²)</th>
<th>λ [W/mK]</th>
<th>U-value [W/m²K]</th>
<th>Embodied energy/m² m3</th>
<th>Thickness for 0.5 (m)</th>
<th>LgCO2 eq/Per m² per Life span</th>
<th>Life span (years)</th>
<th>Environ. Costs/m²</th>
<th>Building costs/m²</th>
<th>Material reuse %</th>
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<td>Glass wool plates + wooden frame</td>
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<td>0.140</td>
<td>187</td>
<td>0.5</td>
<td>0.25</td>
<td>75</td>
<td>94</td>
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<td>234</td>
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<td>0.25</td>
<td>75</td>
<td>7.92</td>
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#### FLAT ROOF INSULATION (m²)

<table>
<thead>
<tr>
<th>FLAT ROOF INSULATION (m²)</th>
<th>λ [W/mK]</th>
<th>U-value [W/m²K]</th>
<th>Embodied energy/m² m³</th>
<th>Thickness for 0.5 (m)</th>
<th>LgCO2 eq/Per m² per Life span</th>
<th>Life span (years)</th>
<th>Environ. Costs/m²</th>
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<tr>
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<td></td>
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<tr>
<td>Isra plates</td>
<td>(upstairs)</td>
<td></td>
<td>2.8</td>
<td>0.2</td>
<td>0.25</td>
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<td>0.20</td>
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<td>75</td>
<td>7.92</td>
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</table>

#### OUTSIDE WINDOW FRAME (per m²)

<table>
<thead>
<tr>
<th>OUTSIDE WINDOW FRAME (per m²)</th>
<th>λ [W/mK]</th>
<th>U-value [W/m²K]</th>
<th>Embodied energy/m³</th>
<th>Dimensions (mm)</th>
<th>LgCO2 eq/Per m² per Life span</th>
<th>Life span (years)</th>
<th>Environ. Costs/m²</th>
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Introduction – Literature research – Design approach – Case study analysis – Building services – Façade analysis – Design – Conclusions
Façade analysis – Materials

Material analysis

- Embodied energy
- Environmental costs
- Building costs
- Data from NIBE database
- For life spans from 15-200 years

Metal façade cladding – Embodied Energy

- Steel, trapezium, galvanized and coated
- Aluminium, profile, not coated
- Aluminium, profile, coated
- Copper felsgevel
Façade analysis – Materials

Sub research question – Best materials

5. What materials can best be used in the façade (for refurbishment) to lower the environmental impact, with a focus on the embodied energy?

For 35 years:

- Cavity insulation: Glasswool
- Roof insulation: EPS plates
- Inside cavity wall: Timber frame
- Outside cavity wall: Mud brick
- Timber cladding: Oak
- Stone cladding: Fibre cement
- Window frame: European softwood
- Door: Tropical multiplex
Façade analysis – Materials

Glass – Energy use

- Operation Energy needed for transmission losses + Solar energy gain (MJ)
- Embodied energy (MJ)
Façade analysis – Materials

Sub research question

6. How can reusing and recycling of (façade) materials contribute to lower the environmental impact, with a focus on the embodied energy?

- No linear relationship between Recyclability and Embodied Energy
- Extra reuse/recyclability per material needs to be assessed, after use
- Reusing existing single glazing in balustrade: 4.4% Embodied Energy savings
Façade analysis - Construction

Façade design approach – Construction layers

- R-values of all layers → Rc-value
- Total Embodied Energy

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<th>R-value</th>
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Introduction – Literature research – Design approach – Case study analysis – Building services – Façade analysis – Design – Conclusions
Façade analysis – Strategies

Façade design approach – Façade strategies & excel calculation

- Extra insulation $R_{façade} = 3.5 \text{m}^2\text{K/W}$ and $R_{roof} = 5 \text{m}^2\text{K/W}$

1. Exterior Upgrading

2. Complete façade replacement

3. Interior upgrading

4. Partial replacement, partial exterior upgrading (Portaal)
Façade analysis – Strategies

Materials for Strategy designs
- Top right apartment of building
- Based on the design of Portaal
- Materials based on analysis
Façade analysis – Strategies

Strategies – Excel calculations

-Simplified designs
-Removal of old materials: Remaining Embodied Energy material = 1/3 initial, the rest can be ‘written off’

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</tbody>
</table>

Introduction – Literature research – Design approach – Case study analysis – Building services – Façade analysis – Design – Conclusions
Façade analysis – Strategies

Energy use per façade part
- Per façade part
- Hand calculations in Excel
- Operation + Embodied Energy for 35 years

Part 2: Energy use 35 years (Embodied + Operation)

Part 8: Energy use 35 years (Embodied + Operation)
Façade analysis - EPC

Façade design approach – EPC calculation

- Rc-values and building services
- Gives output: MJ energy use/year
- Heating, cooling, ventilators, humidification, lighting, domestic hot water
Energy use for whole apartment

- EPC calculations (Operation Energy)
- Hand calculations (Excel file for Embodied Energy)
- EPC = 0.73-0.77

Energy use for each strategy (Embodied + Operational)

Current situation
Façade analysis – Conclusions

Energy use for whole apartment

- EPC calculations (Operation Energy)
- Hand calculations (Excel file for Embodied Energy)
- EPC = 0.73-0.77

Energy use for each strategy (Embodied + Operational)
Façade analysis – Conclusions

Energy use for whole apartment

- EPC calculations (Operation Energy)
- Hand calculations (Excel file for Embodied Energy)
- EPC = 0.73-0.77

Energy use for each strategy (Embodied + Operational)
Conclusions strategies

1. Area of façade remaining
   - Outside Upgrading
     - More transmission area
     - Same energy needed to heat up, same amount of inside space
   - Inside Upgrading
     - Less energy needed to heat up, smaller inside space

2. Rc value of façade
   - Outside Upgrading
     - Total Rc = 4.5
     - $R_{existing} = 1$
     - $R_{new} = 3.5$
   - Façade replacement
     - Total Rc = 3.5

3. Embodied energy of façade
   - Outside Upgrading
     - Embodied Energy new
   - Façade replacement
     - Embodied Energy new + Removal old

4. Compact building
   - Old balcony
     - A large façade area
   - Close off balcony
     - Less façade area, more compact, more inside space
Façade analysis – Conclusions

Façade design approach – Conclusions

Conclusions for new design

- Addition of external insulation and cladding, keep old
- Masonry on south and north façade kept, cavity insulation and inside insulation
- Closing off old balconies
4. DESIGN

**Variation studies**

- Building Services
- Façade strategies

**Final Design**

**Compare designs:**
- Current situation
- Own design
- Portaal's design

**Assessment in:**
- Embodied Energy
- Operation Energy
- Environmental Costs
- Building costs

**Conclusions & Recommendations**
Design – Variation studies

Floor plans - parameters

- Area of insulation needed
- Extra new balcony area
- Cold bridges of balconies
- Area of unheated adjoined rooms
- Energy/costs for elevators
- Inside space area

Old situation

Portaal’s Design

Own Design
Design – Variation studies

Balconies

Variation 1
Least changes

Variation 2
Some changes

Variation 3
Maximum changes

Energy use (Operation + Embodied) 35 years

Energy use (Operation + Embodied) 35 years/m²
Design – Variation studies

Different parameters

- Calculations in EPC for operation energy
- Excel calculations for embodied energy

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Best Value</th>
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<tbody>
<tr>
<td>Glass percentage</td>
<td>20-50%</td>
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<tr>
<td>Infiltration</td>
<td>Qv10 = 0.15 dm³/s/m²</td>
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<tr>
<td>Glass type</td>
<td>Uvalue = 1.4 W/m²K Triple Glazing</td>
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<tr>
<td>Insulation thickness</td>
<td>Rfacaule = 5m²K/W Rroof = 7m²K/W</td>
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<tr>
<td>Thermal mass</td>
<td>Does not matter</td>
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<tr>
<td>PV-cells</td>
<td>Max. 20m2 roof area/apartment EPC = 0.18</td>
</tr>
</tbody>
</table>
Conclusions – For new design

- Gallery balconies, with 2 staircases and 1 elevator

- Closing off old balconies, add new balconies

- Glass percentage 50% or lower

- Extra façade insulation of $R_{facades} = 5 \, \text{W/m2K}$ $R_{roof} = 7 \, \text{m2K/W}$

- Triple glazing

- Infiltration $Q_{v10} = 0.15 \, \text{dm3/s/m2}$
Design – Floor plan

Current situation

Plan Portaal

Source: Portaal

Legend:
- Bathroom
- Toilet
- Kitchen
- Balcony
- Elevator
Design – Floor plan

New Design
Design – West façade

Introduction – Literature research – Design approach – Case study analysis – Building services – Façade analysis – Design – Conclusions
Design – West façade
Design – East façade
Design – Comparison

**Energy use 35 years**

Weighted average of all apartment types

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**Energy use for each strategy (Embodied + Operational), Average of all apartments**

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Current situation
Design – Comparison

Energy use 35 years
Weighted average of all apartment types

Energy use for each strategy (Embodied + Operational), Average of all apartments

Current situation
Plan Portaal
Own Design
Design – Comparison

Energy use 35 years
Weighted average of all apartment types

Energy use for each strategy (Embodied + Operational), Average of all apartments
Design – Comparison

**Energy use 35 years**

Weighted average of all apartment types

![Energy use for each strategy (Embodied + Operational), Average of all apartments](image)

- Current situation
- Own Design
- Energy loss by transmission Portaal
- Plan Portaal
- Energy loss by transmission own design
- Own Design with PV-cells
Design – Comparison

Weighted average all apartments

**Embodied Energy of Designs**

- Own design PV-cells
- Own design
- Design Portaal

- Embodied energy façade
- Embodied energy construction balcony
- Embodied energy PV-cells

**Environmental costs façade, 35 years**

- Own design
- Design Portaal
Weighted average all apartments

- Design approach
- Case study analysis
- Building services
- Façade analysis
- Design

Introduction – Literature research

EPC

- Own design PV-cells
- Own design
- Design Portaal

Energy use (kWh/m²)

- Own design PV-cells
- Own design
- Design Portaal

Operation energy use kWh/year/m²

Building costs façade/apartment

- Own design
- Design Portaal

Building costs (euro)
Design – Conclusions

Main research question
How can the façade of a post-war residential building be refurbished, to make the operation energy and embodied energy (life cycle energy) as low as possible, while also considering other factors that influence the environmental impact?

Conclusion: 3 Steps

- **Building skin**  →  Right balance for: insulation, glass percentage, reusing and keeping of old materials, infiltration, materialisation, closing off cold bridges.  
  **50% energy reduction** compared to current.

- **Building services**  →  Good balance between ventilation, heat output system and heat provision with a high efficiency. Domestic hot water, insulation of pipes, sunshading.  
  **25% energy reduction** compared to current.

- **PV-cells/solar collectors**  →  Limitation due to roof area.  
  **15% energy reduction** extra.
Design – Conclusions

Recommendations

General
-Follow the previous 3 Steps

Portaal
-Portaal uses good materials for the façade, but the insulation values should be higher and they should use PV of Solar cells to lower the energy use.

Research
-Other software than EPC to see exact (heating) energy use and indoor comfort
-More exact values for building costs
-Embodied energy of the building services
-Demolition energy

Design tool
-Also more variations for architectural options in the design approach.
-All different aspects for design integrated into one 3D software tool.
Future research – Integrated design tool
Future research – Integrated design tool
Future research – Integrated design tool
Future research – Integrated design tool
Design – Conclusions

Future research – Integrated design tool
Future research – Integrated design tool

Optimalisation Design against...

- Fire
- Leaves
- Recycle
- Money

Facade Optimalisation
Architect Edition
Thank you for your attention!