Residential buildings with low heat demand.

The impact of design variables on the heat demand of residential buildings in the Netherlands.

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Sustainable Design Graduation Studio

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OVERVIEW

1. INTRODUCTION
2. LITERATURE REVIEW
3. HEAT DEMAND CALCULATION
4. IMPACT STUDIES
5. RE-DESIGN CASE
6. FINAL GUIDELINES
1. INTRODUCTION

1.1 Problem statement

1.2 Research questions

1.3 Methodology
1.1 Problem statement

- End of the fossil fuel age

- Societal demands on energy use

- Designers need to make the right decisions
End of the fossil fuel age

Climate change spurs reduction of greenhouse emissions.

Geopolitical situation favors a move away from fossil fuel dependency.
Societal demands on energy use

Dutch regulations: all new buildings (nearly) energy neutral starting 2021.

Rise of decentralized residential energy supply and storage.
Societal demands on energy use

Reduction of heat demand
Designers need to make the right decisions

The first step is always heat demand reduction (Trias energetic etc.).

Early decisions have large impact for low cost.

The Trias Energetica concept: the most sustainable energy is saved energy.

1. Reduce the demand for energy by avoiding waste and implementing energy-saving measures.
2. Use sustainable sources of energy instead of finite fossil fuels.
3. Produce- and use fossil energy as efficiently possible.
1.2 Research questions

- Main question

- Sub questions
Main question:

What is the impact of design variables on the heat demand of a residential building in the Netherlands and what guidelines can be established for designers?
Sub-questions:

- What design variables are relevant to the heat demand of a building?

- How can the impact of design variables on the heat demand of a building be calculated?

- How can the knowledge of this impact best be applied to an actual building?

- How can guidelines for designers best be formulated?
1.3 Methodology

- Goals

- Process
Goals:

1. Make inventory of relevant design variables through literature review and reference study.

2. Establish and validate a method to calculate the impact of design variables on heat demand.

3. Study the impact of the design variables and apply the conclusions to a case study building.

4. Establish clear guidelines for designers.
Process:

PREPARATION
- Heat Balance Theory
- Software Selection
- Heat Demand Reduction
- Reference Projects

RESEARCH
- Model Validation
- Design Variables
- Impact studies
- Initial Guidelines

DESIGN
- Building Case
- Re-design scenario
- Final Guidelines
2. LITERATURE REVIEW

2.1 Heat balance theory

2.2 Design variables

2.3 Reference projects
2.1 Heat Balance theory

- General Theory
- Transmission Heat Loss
- Solar Heat Gain
General Theory

- Ventilation heat loss
- Infiltration heat loss
- Transmission heat loss

+ Internal heat gain
+ Solar heat gain
Most influenced by building design

- Ventilation heat loss
- Infiltration heat loss
- Transmission heat loss

+ Internal heat gain
+ Solar heat gain
Transmission heat loss

- temperature difference interior-exterior causes heat flow.

- material in between determines rate of flow.
Solar heat gain

+ window surface area

+ solar transmittance of the window

+ angle of sunlight and obstructions
ZonnehAARD woning
Comfortabel, gezond én gezellig
Zuinig met gas én elektriciteit
Bij uitval van de stroom toch warmte
Eenvoudige installaties

Maximaliseer daglicht

Schilisolatie $R_c=5$

Rookgas condensor

Zomer ventilatie

Wasdrogen in serre

Alle ventilatie via de serre

Zomer ventilatie

Natuurlijke ventilatie

Gesloten gashaard

Een nieuw woningconcept met vertrouwde technieken
2.2 Design Variables

- Insulation
- Orientation
- Building Shape
- Sunspaces
Insulation

- Reduces transmission heat loss.

- Walls (Building code: $R_c \geq 4.5$)

- Windows (Building code: $U \leq 1.6$)
Orientation

+ Increases solar heat gain.

+ Benefits from window insulation.
Building shape

- Compactness: less facade surface area per interior volume means less transmission heat loss.

+ Shape factor: more surface facing the sun (south) means more solar heat gain.
Sunspaces

+ Increased solar heat gain potential.

- Acts as buffer zone that decreases transmission heat loss.

+ Can provide comfortable use during cold season.
2.3 Reference projects

- Freiburg SSSH
- BedZED
Freiburg SSSH

Self-Sustaining Solar House

- Expected heat demand: 2 kWh/m²
- high-tech
All rooms have windows oriented towards sun.

Heat storage in walls with TI (transparent Insulation)

PV panels and Solar collectors

Hydrogen power storage

Freiburg SSSH
BedZED
Beddington Zero Energy Development

- Passive house principle
- Combined use: house and office
- No primary heating system
- Centralized backup heating system
- Sunspace
BUILDING PHYSICS

EXPOSED THERMAL MASS

IN SUMMER - PRODUCES COOLING

HIGHLY INSULATED WINDOWS = 0.1 W/m²K
AIRTIGHTNESS = TRIPLE GLAZED
SUN SPACE = 2 AC/HR @ 50Pa

IN WINTER - STORES PASSIVE HEAT GAINS UNTIL NEEDED

= DOUBLE GLAZED TO ROOM & TO OUTSIDE

MINIMUM OVER-SHADING BY ADJACENT BUILDINGS

WORK

CIRCULATION

HOME

SUN SPACE

EXTENSIVE SOUTH FACING GIVING GOOD, PASSIVE SOLAR HEAT GAIN
GLAZED BUFFER SUN SPACE. MINIMUM NORTH GLAZING FOR DAYLIGHT.

NORTH FACING WINDOWS
GOOD DAYLIGHT
MINIMUM SOLAR HEAT GAIN

BedZED

www.TwinnSustainabilityInnovation.com
BedZED

Combined use principle

Internal heat gain

Solar heat gain
3. HEAT DEMAND CALCULATION

3.1 Software selection

3.2 Case building modelling

3.3 Validation calculations
3.1 Software selection

TRANSYS

DesignBuilder

Honeybee
Honeybee

+ Flexible, transparent calculation modules
+ Easy to learn
+ Wide range of relevant input and output
+ Used by other student last year
3.2 Case building modelling

- Zones
- Rhino model
- Honeybee model
3.2 Case building modelling

Zones

Rhino model

Honeybee
Zones
Rhino model

shading elements
4. IMPACT STUDIES

4.1 Study description

4.2 Study results

4.3 Study conclusions
4.1 Study description

- Context
- Variables
- Study Goals
annual kWh/m² heating demand

BENG max.: 25
Passive House max.: 15
Freiburg SSSH: 2
Variables

- Insulation
- Orientation
- Compactness (Shape A)
- Increased sun surface (Shape B)
Goals

1. Quantify impact of variables in terms of kWh/m² heating demand

2. Explore positive effects of sunspaces
4.2 Study results

- Insulation
- Orientation
- Building shape
- Sunspace comparison
Insulation: plain facade

Facade insulation and heat demand

- U=1.6, no HR
- U=0.7, no HR
- U=1.6 with HR
- U=0.7 with HR

- No heat recovery from ventilation air
- 80% heat recovery from ventilation air

KWh/m²

Rc= 4.5 (building code minimum)

<table>
<thead>
<tr>
<th>kWh/m²</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
<th>4.5</th>
<th>5</th>
<th>5.5</th>
<th>6</th>
<th>6.5</th>
<th>7</th>
<th>7.5</th>
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</thead>
<tbody>
<tr>
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<td>76.5</td>
<td>72.4</td>
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<td>66.7</td>
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<td>62.3</td>
<td>62.0</td>
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<td>58.5</td>
<td>58.2</td>
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<td>57.6</td>
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<td>29.3</td>
<td>25.6</td>
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<tr>
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<td>31.9</td>
<td>25.0</td>
<td>21.4</td>
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<td>15.0</td>
<td>14.5</td>
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<td>13.7</td>
<td>13.4</td>
<td>13.2</td>
<td>12.9</td>
<td>12.7</td>
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</table>
Insulation: sunspaces

<table>
<thead>
<tr>
<th></th>
<th>U= 5.8</th>
<th>U= 3.8</th>
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<th>U= 0.7</th>
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<td>18.9</td>
<td>17.0</td>
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<td>14.9</td>
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<tr>
<td>U interior= 0.7</td>
<td>17.7</td>
<td>16.6</td>
<td>16.3</td>
<td>15.4</td>
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</tbody>
</table>

\[ \text{kWh/m}^2 \]
Orientation: plain facade

Heat demand for varying orientations

No heat recovery from ventilation air

80% heat recovery from ventilation air

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Heat Demand (kWh/m²)</th>
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</thead>
<tbody>
<tr>
<td>N</td>
<td>68.4 68.3 67.9 67.2 66.3 65.1 63.8 62.5 61.2 60.0</td>
</tr>
<tr>
<td>NE</td>
<td>69.4 69.3 68.9 68.2 67.3 66.1 64.9 63.6 62.3 61.0</td>
</tr>
<tr>
<td>E</td>
<td>69.4 69.3 68.9 68.2 67.3 66.1 64.9 63.6 62.3 61.0</td>
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<td>SE</td>
<td>69.4 69.3 68.9 68.2 67.3 66.1 64.9 63.6 62.3 61.0</td>
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<tr>
<td>S</td>
<td>69.4 69.3 68.9 68.2 67.3 66.1 64.9 63.6 62.3 61.0</td>
</tr>
<tr>
<td>SW</td>
<td>69.4 69.3 68.9 68.2 67.3 66.1 64.9 63.6 62.3 61.0</td>
</tr>
<tr>
<td>W</td>
<td>69.4 69.3 68.9 68.2 67.3 66.1 64.9 63.6 62.3 61.0</td>
</tr>
<tr>
<td>NW</td>
<td>69.4 69.3 68.9 68.2 67.3 66.1 64.9 63.6 62.3 61.0</td>
</tr>
</tbody>
</table>

For heat recovery:

<table>
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<th>Orientation</th>
<th>Heat Demand (kWh/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>U=1.6 68.4 68.3 67.9 67.2 66.3 65.1 63.8 62.5 61.2 60.0</td>
</tr>
<tr>
<td>NE</td>
<td>U=0.7 59.6 59.5 59.2 58.7 57.9 56.9 55.8 54.7 53.5 52.5</td>
</tr>
<tr>
<td>E</td>
<td>U=1.6 68.4 68.3 67.9 67.2 66.3 65.1 63.8 62.5 61.2 60.0</td>
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<tr>
<td>SE</td>
<td>U=0.7 59.6 59.5 59.2 58.7 57.9 56.9 55.8 54.7 53.5 52.5</td>
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<td>S</td>
<td>U=1.6 68.4 68.3 67.9 67.2 66.3 65.1 63.8 62.5 61.2 60.0</td>
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<tr>
<td>SW</td>
<td>U=0.7 59.6 59.5 59.2 58.7 57.9 56.9 55.8 54.7 53.5 52.5</td>
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<tr>
<td>W</td>
<td>U=1.6 68.4 68.3 67.9 67.2 66.3 65.1 63.8 62.5 61.2 60.0</td>
</tr>
<tr>
<td>NW</td>
<td>U=0.7 59.6 59.5 59.2 58.7 57.9 56.9 55.8 54.7 53.5 52.5</td>
</tr>
</tbody>
</table>

- U=1.6
- U=0.7
- U=1.6 + HR
- U=0.7 + HR
Orientation: plain facade

Gain or loss due to glass

- 80% glass U=1.6
- 20% glass U=1.6
- 80% glass U=0.7
- 20% glass U=0.7

10% decrease potential
30% decrease potential
Orientation: sunspaces

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>NE</th>
<th>E</th>
<th>SE</th>
<th>S</th>
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<td>U ext=0.7</td>
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<td>15.8</td>
<td>15.8</td>
<td>15.6</td>
<td>15.4</td>
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<tr>
<td>no sunspace</td>
<td>15.5</td>
<td>15.5</td>
<td>15.5</td>
<td>14.9</td>
<td>13.7</td>
</tr>
</tbody>
</table>

Heat demand for varying orientations

- sunspace, U exterior= 1.6
- sunspace, U exterior= 0.7
- plain facade, U= 0.7
Building Shape: plain facade

extra variable: % glass in facade
Building Shape: sunspaces

Shape A vs. B (U= 1.6)

<table>
<thead>
<tr>
<th></th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
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<tbody>
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<td>A, U=1.6</td>
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<td>16.6</td>
<td>16.5</td>
</tr>
<tr>
<td>B, U=1.6</td>
<td>15.5</td>
<td>15.2</td>
<td>14.9</td>
<td>14.6</td>
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</tbody>
</table>

Shape A vs. B (U= 0.7)

<table>
<thead>
<tr>
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<th>60%</th>
<th>80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, U=0.7</td>
<td>16.4</td>
<td>15.7</td>
<td>15.5</td>
<td>15.3</td>
</tr>
<tr>
<td>B, U=0.7</td>
<td>13.6</td>
<td>12.2</td>
<td>11.4</td>
<td>11.1</td>
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</tbody>
</table>
Comparison studies: Shape A
A - Sunspace

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<tbody>
<tr>
<td>U=1.6</td>
<td>7.1</td>
<td>17.3</td>
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</tr>
<tr>
<td>U=0.7</td>
<td>4.8</td>
<td>17.2</td>
<td>4.8</td>
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</tbody>
</table>

why?
Operative temperature

**Balconies**

**Sunspaces**
Plain facade

Shape A temperatures

Sunspaces
Shape A temperatures: sunspace
Comparison studies: Shape B

- **B - Plain facade**

- **B - Balconies**

- **B - Sunspaces**
Comparison studies: overview
4.3 Study conclusions

- Insulation
- Orientation
- Building Shape
- Sunspaces
Heat recovery has huge impact, insulation over Rc = 4.5 has very limited impact.
Orientation has extreme impact.

Gain or loss due to glass

Orientation

- 80% glass U=1.6
- 80% glass U=0.7
- 20% glass U=1.6
- 20% glass U=0.7

10% decrease potential
30% decrease potential

Orientation has extreme impact.
Building shape

*Shape B, sun surface far outweighs compactness when well insulated.*
Sunspaces

Shape B comparison

<table>
<thead>
<tr>
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<th>kWh/m²</th>
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<tbody>
<tr>
<td>Plain U=1.6</td>
<td>10.6</td>
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<tr>
<td>Balcony U=1.6</td>
<td>14.4</td>
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<tr>
<td>Sunspace U=1.6</td>
<td>7.9</td>
</tr>
<tr>
<td>Plain U=0.7</td>
<td>5.7</td>
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<tr>
<td>Balcony U=0.7</td>
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<tr>
<td>Sunspace U=0.7</td>
<td>5.7</td>
</tr>
</tbody>
</table>
Sunspaces

Operative Temperature for SUNA (°C) - Hourly
AMSTERDAM - NLD IWEC Data
1 JAN 1:00 - 31 DEC 24:00
Sunspaces

Flexible use

Summer

Winter
5. RE-DESIGN CASE

5.1 Re-Design Process

5.2 Re-design Modelling

5.3 Analysis
5.1 Re-design process

- Case building
- Design steps
- Final re-design
Case building
Design steps

Step 1: Orientation change

Step 2: Shape change (A to B)

Step 3: Sunspace and sunshade

Step 4: Improve Insulation
Final re-design

Original design

Re-design
Re-design floorplan
5.2 Re-design modelling

- Zones
- Models
Validation model
- many zones
- all floors

Final model
- one zone per apartment
- one floor
Models

Original design

Re-design
5.3 Analysis

- Results
- Conclusions
Results

1. **U glass**
   - 25.4 kWh/m² (U=1.6)
   - 17.7 kWh/m² (U=0.7)

2. **S glass**
   - 18.6 kWh/m² (U=1.6)
   - 12.3 kWh/m² (U=0.7)

3. **Shape B + sunspace**
   - 14.2 kWh/m² (U=1.6)
   - 8.4 kWh/m² (U=0.7)

4. **Facade insulation**
   - 6.4 kWh/m² (U=0.7)

**Absolute reduction [kWh/m²]**
1. -U glass = 7.7
2. S glass = 5.4
3. Shape B = 3.9
4. Rc = 2

**Relative reduction**
1. -U glass = 30%
2. S glass = 31%
3. Shape B = 31%
4. Rc = 24%
Ranked by highest (absolute) impact on heat demand:

1. change of U value glass from 1.6 to 0.7
2. South facing glass
3. Shape change A to B
4. Facade insulation
6. DESIGN GUIDELINES

6.1 Guideline development

6.2 Design Guidelines

6.3 Final words
6.1 Guideline development

- Criteria
- Approach
- Guidelines application
Criteria

• Easily readable

• Translate technical story into design story

• Short but precise

• Link to reasearch

• Explain why
Approach

1. Priority List as overview
   - readable
   - short
   - design story

2. Explanation per priority point
   - link to research
   - explain why
6.2 Design Guidelines

- Priority points
- Explanation per point
1. Have as much glazing face (roughly) South.

2. Increase insulation of glazing.

3. Maximize sun surface.

4. Sunspaces if applicable.

5. Increase insulation value of facade.
Point 1. Glass facing south

Glass facing south has massive heat demand reduction potential.
Point 2. Insulation of glazing

50% savings:
When maximizing solar gain, a U value decrease from 1.6 to 0.7 can cut heat demand in half.
Point 3. Sun surface

Sun surface greatly outweighs compactness when window insulation value is high.
Point 4. Sunspaces

*Heat buffer, reduces heat loss*

*Flexible use*

*Advantages of keeping heat out in summer and drawing it in in winter.*
Point 5. Insulation of facade

Building code minimum Rc value is 4.5. Impact of increase beyond 4.5 is minimal.
6.3 Final Words

- Reflection
- Future study recommendations
Reflection

- better research structure
- more illustrations!
Future study recommendations
Fin