Multi-objective Optimization of Fenestration Design in Residential spaces
The case of MKB, Greenhouse, Malmö, Sweden

Iason Bournas¹ & Ludvig Haav¹

¹Energy and Building Design, Department of Architecture and the Built Environment, LTH, Lund, Sweden
Objective 1
(e.g. light dependency)

Objective 2
(e.g. heating demand)

View Zone
MKB Greenhouse

Feby Gold
Miljöbyggnad certification
(for daylight)

U-value
Walls: 0.15 W/m²K
Windows: 0.80 W/m²K

Infiltration rate: 0.3 l/s/m²
Specific energy use: 48 kWh/m²

(Image: Jaenecke Arkitekter AB)
STUDY OBJECT

1. Northwest (NW) apartment: 68 m²
2. Northeast (NE) apartment: 68 m²
3. South (S) apartment: 85 m²

(Image: Jaenecke Arkitekter AB)
1. NW APARTMENT
Area: 68 m²

Fenestration study in:
Living room
Bedroom
METHOD - Rooms & Fenestration zones

ABCD Bedroom perigram
DEFG Living room perigram
METHOD - Rooms & Fenestration zones

Fenestration zones:
One for the bedroom (F1)
Four for the living room (F2, F3, F4 & F5)
METHOD - Rules and boundaries of fenestration

A window is calculated if:

1. It is larger than $0.5 \times 0.5$ m$^2$ or $0.5 \times 1.0$ m$^2$
2. It is a convex polygon
3. It belongs (at least partly) in the View Zone
RADIANCE: Accuracy → Time (Grid spacing, ambient bounces)

Comparison of "Reference case" with different grid setups

<table>
<thead>
<tr>
<th>T_ref = 22 min</th>
<th>Volumetric difference ΔVol and simulation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Bounces</td>
<td></td>
</tr>
<tr>
<td>Position</td>
<td>Low</td>
</tr>
<tr>
<td>0.50</td>
<td>6</td>
</tr>
<tr>
<td>0.75</td>
<td>7</td>
</tr>
<tr>
<td>1.00</td>
<td>6</td>
</tr>
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</tr>
<tr>
<td>1.50</td>
<td>10</td>
</tr>
<tr>
<td>1.75</td>
<td>10</td>
</tr>
<tr>
<td>2.00</td>
<td>11</td>
</tr>
<tr>
<td>2.25</td>
<td>21</td>
</tr>
<tr>
<td>2.50</td>
<td>21</td>
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</table>

<table>
<thead>
<tr>
<th>Grid size / m</th>
<th>DA deviation units</th>
<th>Time / min</th>
</tr>
</thead>
</table>

FULL REPORT AT: https://lup.lub.lu.se/student-papers/search/publication/8885759
PROBLEM - Large number of possible fenestration alternatives

Multiple window variables lead to a vast solution space*

This thesis case: 7,3 million solutions

11 minutes per solution

= 153 years of simulation time

*The total of solutions plotted on a cartesian plane
SOLUTION - Use of Genetic Algorithm

GENES (A, B, C, D)

A. Width

B. Position

C. Head height

D. Sill height

CHROMOSOME

PHENOTYPE
GENETIC ALGORITHM - Exemplified optimization process

STEP 1
Initial random generation

Objective 1
(e.g. light dependency)

Objective 2
(e.g. heating demand)

Objectives need to be minimized

Origin point
Solutions should converge towards it
GENETIC ALGORITHM - Exemplified optimization process

STEP 1
Initial random generation

STEP 2
Fitness assignment

Objective 1
(e.g. light dependency)

Objective 2
(e.g. heating demand)

Solutions are ranked based on performance to objectives

Origin point
Solutions should converge towards it
GENETIC ALGORITHM - Exemplified optimization process

**STEP 1**
Initial random generation

**Objective 1**
(e.g. light dependency)

**Objective 2**
(e.g. heating demand)

**STEP 2**
Fitness assignment

"Elite"

**STEP 3**
Mating & Variation

Gene interaction
between optimum solutions

Origin point
Solutions should converge towards it
GENETIC ALGORITHM - Exemplified optimization process

STEP 1
Initial random generation

STEP 2
Fitness assignment

STEP 3
Mating & Variation

STEP 2
Fitness assignment

Objective 1
(e.g. light dependency)

Objective 2
(e.g. heating demand)

Towards
2nd Generation
re-assessment of performance

Origin point
Solutions should converge towards it
RESULTS - Living room.

Heating/daylighting Optimization

**GENERATION 5**

- LD150lx (%)
- Specific energy use (kWh/m²)
- Generations 0 - 5
- Optimum solutions
- Final pareto

**WWR**

- LD150lx (%)
- Specific energy use (kWh/m²)
- WWR range
  - <10%
  - 10%-20%
  - 20%-30%
  - 30%-40%
  - 40%-50%
  - 50%-60%
  - 60%-70%
  - >70%
  - Pareto

Mutation
- Local Optimum
- Global Optimum
RESULTS - Living room.

Heating/daylighting Optimization

GENERATION 5

LD150lx (%)

Specific energy use (kWh/m²)

not generating

oversupply

WWR

LD150lx (%)

Specific energy use (kWh/m²)

WWR range

<10%

10%-20%

20%-30%

30%-40%

40%-50%

50%-60%

60%-70%

>70%

Pareto

mutation

Local Optimum

Global Optimum
RESULTS - Living room.

Heating/daylighting Optimization

![Graphs showing energy use and LD150lx for generations 5, 10, 15, and 20.]

- Generation 5
- Generation 10
- Generation 15
- Generation 20

Specific energy use (kWh/m²) vs. LD150lx (%) graphs for each generation, highlighting optimum solutions, final pareto, and older solutions.
RESULTS - Living room.

For WWR < 20 %, F3 is populated.

Then F5 is also utilized.

For WWR > 40 % the Northern fenestration zone must be used, three windows in total.

For WWR > 60 % four windows are necessary, no daylight improvement.

Heating/daylighting Optimization

West apartment - living room

LD150lx (%)

WWR = 15%

WWR range
○ 10%-20%
● 20%-30%
× 30%-40%
△ 40%-50%
◆ 50%-60%
□ 60%-70%
+ >70%

Specific energy use (kWh/m²)
### RESULTS - Bedroom.

<table>
<thead>
<tr>
<th>WWR</th>
<th>NORTH</th>
<th>EAST</th>
<th>WEST</th>
<th>SOUTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%-20%</td>
<td>10%</td>
<td>10%</td>
<td>16%</td>
<td>16%</td>
</tr>
<tr>
<td>20%-30%</td>
<td>23%</td>
<td>23%</td>
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<td>39%</td>
<td>39%</td>
<td>39%</td>
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<tr>
<td>40%-50%</td>
<td>47%</td>
<td>42%</td>
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</tr>
<tr>
<td>50%-60%</td>
<td>52%</td>
<td>52%</td>
<td>52%</td>
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</tr>
<tr>
<td>60%-70%</td>
<td>62%</td>
<td>62%</td>
<td>78%</td>
<td>78%</td>
</tr>
<tr>
<td>&gt;70%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Heating/daylighting Optimization**

![Diagram of a room with dimensions and shaded areas indicating energy optimization.](image)

Same for the bedroom
THANK YOU

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Iason Bournas\textsuperscript{1} & Ludvig Haav\textsuperscript{1}

\textsuperscript{1}Energy and Building Design, Department of Architecture and the Built Environment, LTH, Lund, Sweden

Supervisor: Marie-Claude Dubois, Energy and Building Design, LTH
Examiner: Maria Wall, Energy and Building Design, LTH