Integrating **Natural Ventilation** within an optimization process of energy performance in the early design stage

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BACKGROUND RESEARCH
TOTAL PRIMARY ENERGY USE

- Industry (18%)
- Residential (31%)
- Agriculture (1.3%)
- Transport (42%)
- Commercial (18%)
IMPORTANCE OF EARLY DESIGN STAGES

Cost effectiveness (%)

Time: Concept design to Construction (%)

Conceptual design

Effect

Cost

Design development

Construction

[Graph showing the importance of early design stages in terms of cost effectiveness and time from concept design to construction.]
WHY USING BPO?

It informs the design process and gives evaluation of design strategies.

It is able to handle big amount of data and extract useful information from data.

Provides a number of solutions for engineering problems related to competing performances of a design.
OPTIMIZATION

Optimization Program

OBJECTIVE FUNCTIONS

OPTIMIZATION SETTINGS

SIMULATION OUTPUT RETRIEVAL

Optimization program

STOPPING CRITERION MET?

YES

NO

OPTIMIZATION RESULTS

Results

Run simulation

Parameters

Building Simulation Program

Background research
Evaluation tools
Integrated optimization process
Case study
Conclusions
UTOPIA POINT

- "Utopia" point
- Closest point
- Dominated solutions
- Pareto front

Objective function 1
Objective function 2
LEVELS OF APPROXIMATION

- Functional approximation
- Problem approximation
LEVELS OF APPROXIMATION

Functional approximation
- Objective functions
- Optimization algorithm

Problem approximation
- Evaluation method
LEVELS OF APPROXIMATION

Functional approximation
- Objective functions
- Optimization algorithm

Problem approximation
- Evaluation method
OPTIMIZATION IN ACADEMIC FIELD

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</table>

Integrated approach: a process in which natural ventilation rates are calculated by using COPSS

Non-integrated approach

Non-integrated approach

Integrated approach: A step-by-step process is proposed, in which every parameter is optimized separately. In this way the parameters defining the design are not directly related with each other losing possibilities for energy savings

Non-integrated approach

Non-integrated approach
NATURAL VENTILATION EFFECTS ON THERMAL COMFORT

Mean operative outdoor temperature (°C)

Comfort temperature (°C)

NATURAL VENTILATION EFFECTS ON THERMAL COMFORT

Background research
Evaluation tools
Integrated optimization process
Case study
Conclusions
OPTIMIZATION IN REAL PRACTICE

- Conceptual phase
- Design development
- Technical development

- Optimization for solar radiation
  - No thermal analysis/natural ventilation
- Optimization of specific problems
  - Not integrated approach
  - Thermal analysis/natural ventilation

- ARUP
- UNS
- DPA
- UNS
CONCLUSIONS

Missing integrated approach in academic field and real practice
RESEARCH QUESTION

To what extent can the optimization of natural ventilation strategies in the early design stage improve energy performance and thermal comfort of a design for an office building?

Sub-questions

• To what extent can embedding natural ventilation strategies into an optimization process affect its final outputs in terms of building performance and layout?

• To what extent can a holistic approach be beneficial for an optimization process of energy performance in the early stages of a design?
The implementation of natural ventilation strategies should occur early in the design stages and it should be embedded into a multi-criteria optimization process in order to achieve low energy performance in buildings.

The focus is on the design form finding in the early stages integrating passive design strategies, with a focus on natural ventilation strategies for passive cooling. The process is meant to be for temperate and hot climates, and it will be tested on a case study located in Amsterdam, the Netherlands.
I.O.P. - METHODOLOGY

1. Selection of evaluation criteria
2. Research on building performance requirements for office buildings
3. Definition of objective functions
4. Identification of the design variables and their specific constraints
5. Selection of building performance simulation tools and making of a building model
6. Selection of an optimization algorithm
EVALUATION CRITERIA

Evaluation criteria for Energy concept

- Economy (life cycle costs)
- Society (acceptance)
- Architecture (quality of design)
- CO2 emissions
- Embodied energy
- Energy need
- Visual comfort
- Thermal comfort
- Indoor air quality
- Acoustic comfort

Active strategies
- Orientation (sun+wind)
- Exterior Wall to Floor Area ratio
- Daylight access
- Solar protection
- Passive solar
- Natural ventilation

Passive strategies
- Envelope Thermal protection
- Thermal mass
- Thermal cooling
- Ventilation cowl
- Venturi cowl
- Night ventilation
- Stack effect
- Cross ventilation
- Solar chimney
- Double skin facade
- Single-sided ventilation
NATURAL VENTILATION SOLVER
EXISTING TOOLS

Accuracy

- Detailed (slow)
  - Isothermal CFD (Fluent, Phoenics, DB, etc)
  - CFD (Fluent, Phoenics, DB, etc)
  - Zonal model (E+, Esp-r, POMA, etc)

- Rough (fast)
  - Multi-zone model (COMIS, CONTAM, etc)
  - CoolVent (multi-zone model)

Coupled airflow and thermal analysis

- yes
- no
NATURAL VENTILATION SOLVER - PRINCIPLE

- Heat balance building
- Air displacement equations
- n iterations
NATURAL VENTILATION SOLVER - WORKFLOW

- Wind pressure coefficient
- Wind pressure difference
- Effective opening area
- Building program
- Equipment, lighting + people gains density
  - Total floor area
  - Interior surfaces total area
  - Opaque surfaces total area
  - Glazed surfaces total area
- Building geometry
- Walls U-value
- Glazing U-value
- Glazing SHGC
- Weather data
- Monthly average temperatures
- Airflow & Temperature
- Average airflow rate
- Internal heat gains calculation
- Total (transmission heat transfer calculation)
- Solar radiation calculation
- Glazed elements (transmission heat transfer calculation)
- Opaque elements (transmission heat transfer calculation)
NATURAL VENTILATION SOLVER - SCENARIOS

Atrium/solar chimney

Atrium/solar chimney + DSF

Cross ventilated building
1. Wind pressure coefficient
2. Wind pressure difference
3. Effective opening area
4. Airflow&Temperature
5. Neutral plane
6. Inflow check
NATURAL VENTILATION SOLVER - ASSESSMENT 1

Evaluation tools

Airflow & Temperature
CoolVent

Background research
Integrated optimization process
Case study
Conclusions
NATURAL VENTILATION SOLVER - ASSESSMENT 2

Mean Radiant Temperature in July at 12:00 hours
Minimum: 32°C Maximum: 36.3°C
Room (Analytic Plane at z = 20.00m)
HEATING AND COOLING NEED
HEATING & COOLING NEED - PRINCIPLE

Main assumptions:

• Building as one zone
• Only sensitive heat considered
• Dynamic effects with utilization factors
HEATING AND COOLING NEED - WORKFLOW

- Building program
  - Requirements for ventilation rates (no hot months)
  - Equipment, lighting + people gains density
  - Total floor area
  - Interior surfaces total area
  - Opaque surfaces total area
  - Glazed surfaces total area

- Building geometry
  - Walls U-value
  - Glazing U-value
  - Glazing SHGC

- Weather data
  - Monthly average temperatures

- Glazing SHGC extracted

- Opaque elements transmission heat transfer calculation
- Glazed elements transmission heat transfer calculation

- Solar radiation calculation

- Internal heat gains calculation

- Total transmission heat transfer calculation

- Heating & Cooling need calculation

- Monthly results

**Evaluation tools**
HEATING & COOLING NEED - COMPONENTS

Heat transfer by transmission

Solar heat flux

Internal heat gains

Heat & Cooling need
INTEGRATED OPTIMIZATION PROCESS
ALGORITHMIC PROCESS - PRINCIPLE
ALGORITHMIC PROCESS - PRINCIPLE

- Data
- Data
- Data
- Data
- Data
- Data

Algorithm
ALGORITHMIC PROCESS - PRINCIPLE

Data → Algorithm → Data → Algorithm → Data → Algorithm → Data → Algorithm → Data → Algorithm
ALGORITHMIC PROCESS - PRINCIPLE

Data → Algorithm → Output

Data → Algorithm → Output

Data → Algorithm → Output

Data → Algorithm → Output

Data → Algorithm → Output

Data → Algorithm → Output
I.O.P. - PRINCIPLE

**Integrated optimization process**
I.O.P. - PRINCIPLE
I.O.P. - PRINCIPLE

Parameter
Parameter
Parameter
Parameter
Parameter

Daylight
Energy need
Natural ventilation

Output
Output
Output

Objective function 1
Objective function 2
Objective function 3

Optimization algorithm
I.O.P. - PRINCIPLE

Integrated optimization process
DEVELOPED ALGORITHMIC PROCESS
DEVELOPED ALGORITHMIC PROCESS
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Integrated optimization process
DEVELOPED ALGORITHMIC PROCESS
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DEVELOPED ALGORITHMIC PROCESS
DEVELOPED ALGORITHMMIC PROCESS
CASE STUDY PART 1: INTRODUCTION
BUILDING LOCATION

Name: Atrium building
Location: Amsterdam - Zuidas
Total floor area: 45000 m²
BUILDING PROGRAM

Ground floor

Fifth floor

Restaurant services
Atrium space
Restaurant
Catering
Commercial rooms
Services
Emergency stairs
Technical rooms
CURRENT INDOOR ENVIRONMENTAL ISSUES

Visual discomfort in the first 6 storeys

Thermal discomfort in atrium A
OPTIMIZATION SCENARIOS

Scenario 1 - Whole building optimization

Scenario 2 - optimization Atrium A
OPTIMIZATION STRATEGIES
OPTIMIZATION STRATEGIES

Before

After
DESIGN CONSTRAINTS

Total surface area: 45000 m²
DESIGN VARIABLES
DESIGN VARIABLES

Rotation angle

range: $0 < X < 20^\circ$
DESIGN VARIABLES

Rotation angle
range: $0 < X < 20^\circ$

Vectorial length of movement
range: $0 < X < 10m$
### DESIGN VARIABLES

- **Rotation angle**
  - range: $0 < X < 20^\circ$

- **Vectorial length of movement**
  - range: $0 < X < 10\text{m}$

- **Window to Wall ratio**
  - range: $20\% < X < 80\%$
**DESIGN VARIABLES**

- **Rotation angle**
  - range: $0 < X < 20^\circ$

- **Vectorial length of movement**
  - range: $0 < X < 10\text{m}$

- **Window to Wall ratio**
  - range: $20\% < X < 80\%$

- **Atrium roof height**
  - range: $2 < X < 5\text{m}$
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<th>DESIGN VARIABLES</th>
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<td>Solar Heat Gain Coefficient</td>
<td>range: $0.4 &lt; X &lt; 0.9$</td>
<td>U-value exterior walls</td>
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<td>range: $0.2 &lt; X &lt; 0.5$</td>
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<tr>
<td></td>
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<td>U-value windows</td>
</tr>
<tr>
<td></td>
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<td>Discrete range: $0.5, 1, 1.5, 2, 3$</td>
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</table>
DEPENDENT PARAMETERS

- **Atrium shape and size**
  - Total area: 40% of total area

- **Total number of floors**

- **Ventilation openings facade (vents):** $4m^2$
  - Ventilation openings Atrium roof: $12m^2$
BASE CASE ANALYSIS

Ventilation openings facade (vents): 4 m²
Ventilation openings Atrium roof: 12 m²

Lux levels
UDI: 42/180 pts

Heating need:
- block A
- block B
- block C

Cooling need:
- block A
- block B
- block C

kWh/m²a

Heating need

Cooling need

Case study
BASE CASE ANALYSIS

- **Cooling need**
  - kWh/m²a
  - Comparison of block A, B, and C

- **Heating need**
  - kWh/m²a
  - Comparison of block A, B, and C
BASE CASE ANALYSIS

Cooling need

Heating need

Improvement of calculation

Case study
IMPROVEMENT OF THE CALCULATIONS

WHOLE YEAR
- National standard mechanical ventilation rates

SUMMER MONTHS
- Calculated rates of natural ventilation

Heating calculation

Cooling calculation

Total energy need

National standard mechanical ventilation rates
Calculated rates of natural ventilation

WHOLE YEAR

SUMMER MONTHS

Heating calculation

Cooling calculation

Total energy need

Improvement of the calculations
OBJECTIVE FUNCTIONS

1. Minimize: Heating and Cooling need (kWh/m²a)

2. Minimize: Percentage of People Dissatisfied (%)

3. Minimize: points with lux > 2000
   points with lux < 500
ANALYSIS 1

Parameters
- Ventilation schedule
- Orientation
- Building geometry
- Ventilation openings
- U-value
- SHGC
- Window to Wall Ratio
- Shading

Outputs
- Heating and cooling need (kWh/m²a)
- Thermal comfort level (%)
- Useable Daylight Illuminance (%)

Case study
ANALYSIS 1

Parameters
- Ventilation schedule
- Orientation
- Building geometry
- Ventilation openings
- U-value
- SHGC
- Window to Wall Ratio
- Shading

Outputs
- Heating and cooling need (kWh/m²a)
- Thermal comfort level (%)
- PPD Adapative
- Useful Daylight Illuminance (%)

Parameters: Shading, Outputs: Useful Daylight Illuminance (60%)
ANALYSIS 1 - OPTIMIZATION RESULTS

Search space - UDI* vs Heating & Cooling

Fitness Pareto front solutions

kWh/m²a

number of points

"Utopia" point

Daylight autonomy

38.5
42.83
Heating & Cooling

"Utopia" point

11

13

3

4

6

8

1

14

2

9

5

10

12

7

Search space - UDI* vs Heating & Cooling
ANALYSIS 1 - SELECTED SOLUTION

Search space - UDI* vs Heating & Cooling

"Utopia" point

Daylight autonomy

Solution 11
ANALYSIS 1 - SELECTED SOLUTION

Cooling need - before

Heating need - before

Solution 11
Providing Natural Ventilation

ANALYSIS 1 - SELECTED SOLUTION

Cooling need - before

Cooling need - after

Heating need - before

Heating need - after
ANALYSIS 2

Parameters
- Ventilation schedule
- Orientation
- Building geometry
- Ventilation openings
- U-value
- SHGC
- Window to Wall Ratio
- Shading

Outputs
- Heating and cooling need (kWh/m²a)
- Thermal comfort level (%)
- Useful Daylight Illuminance (%)

Case study
ANALYSIS 2 - OPTIMIZATION RESULTS

Search space - Isometric view

Solution 16

“Utopia” point

Daylight autonomy 2

PPD 2: 53.29

Heating & Cooling: 54

39.3

38.0

35.91

Solution 16
ANALYSIS 3

Parameters
- Ventilation schedule
- Orientation
- Building geometry
- Ventilation openings
- U-value
- SHGC
- Window to Wall Ratio
- Shading

Outputs
- Heating and cooling need (kWh/m²a)
- Thermal comfort level (%)
- Useful Daylight Illuminance (%)

Case study
ANALYSIS 3 - OPTIMIZATION RESULTS

Fitness Pareto front solutions

Search space - UDI* vs Heating&Cooling
ANALYSIS 3 - SELECTED SOLUTION

U-value walls blocks A,B,C: 0.2, 0.4, 0.3

U-value windows blocks A,B,C: 1, 1.5, 2

SHGC blocks A,B,C: 0.3, 0.4, 0.5

Cooling need

Heating need
COMPARISON

kWh/m²a  %
number of points
CASE STUDY PART 3: SCENARIO 2
NEUTRAL PLANE

- Top openings: 18m²
- Internal openings: 9m²

- Top openings: 11m²
- Internal openings: 9m²

- Top openings: 5m²
- Internal openings: 18m²
DESIGN VARIABLES

- **Depth**
  - range: $0.1 < X < 0.9$ (m)

- **Spacing**
  - range: $0.1m < X < 0.9$ (m)

- **Rotation angle**
  - range: $-45 < X < 45$ (°)
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<th>U-value envelope</th>
<th>Ventilation openings</th>
<th>Ventilation schedules</th>
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<td>range: 0.5 &lt; X &lt; 2 (W/m²K)</td>
<td>Top openings: 0 &lt; X &lt; 18</td>
<td>range: 0 &lt; X &lt; 8 (hrs)</td>
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<td>Int. openings: 0 &lt; X &lt; 10</td>
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<td></td>
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<td>Ext. openings: 0 &lt; X &lt; 18 (m²)</td>
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</table>
DESIGN CONSTRAINT
OBJECTIVE FUNCTIONS

1. Minimize: Heating and Cooling need (kWh/m²a)

2. Minimize number of hours with thermal discomfort (hrs)

3. Maximize points with lux < 2000
   points with lux > 300
**BASE CASE ANALYSIS**

**Current situation**
- UDI*: 46.3%
- Adapt. comfort: 53 hrs

**+ Natural ventilation**
- UDI*: 46.3%
- Adapt. comfort: 53 hrs

**+ Shadings**
- UDI*: 49.0%
- Adapt. comfort: 45 hrs

**+ Natural ventilation + Shadings**
- UDI*: 49.0%
- Adapt. comfort: 45 hrs

*UDI* = User Demand Index

**Graph:**
- kWh/m²a
- 600 kWh/m²a at current situation
- 380 kWh/m²a after optimization (32% reduction)

**Case study**
BASE CASE ANALYSIS

Current situation + Natural ventilation + Shadings + Natural ventilation + Shadings

-32%

kWh/m²a

kWh/m²a

-32%
ANALYSIS 1

Parameters:
- Ventilation schedule
- Orientation
- Building geometry
- Ventilation openings
- U-value
- SHGC
- Window to Wall Ratio
- Shading

Outputs:
- Heating and cooling need (kWh/m²a)
- PPD Adaptive
- Thermal comfort level (%)
- Useful Daylight Illuminance (%)
U-value glazing envelope: 0.6 W/m² K
SHGC facade: 0.3
SHGC roof: 0.2
Ventilation openings: 16, 7, 14 m²
Ventilation schedules: 7, 5, 6 hrs
ANALYSIS 1 - SELECTED SOLUTION

U-value glazing envelope: 0.6 W/m²K

SHGC facade: 0.3

SHGC roof: 0.2

Ventilation openings: 16, 7, 14 m²

Ventilation schedules: 7, 5, 6 hrs

UDI*: 98.4%

Adaptive comfort: 53/80 hrs

kWh/m²a

Cases 1-12
**ANALYSIS 2**

**Parameters**
- Ventilation schedule
- Orientation
- Building geometry
- Ventilation openings
- U-value
- SHGC
- Window to Wall Ratio
- Shading

**Outputs**
- Heating and cooling need (kWh/m2a)
- Thermal comfort level (%)
- Useful Daylight Illuminance (%)

**Case study**
ANALYSIS 2 - OPTIMIZATION RESULTS

Search space - UDI* vs Heating&Cooling

“utopia” point

103
ANALYSIS 2 - OPTIMIZATION RESULTS

- %
- kWh/m²a
- hrs

**Case study**
U-value glazing envelope: 0.6 W/m²K

SHGC facade: 0.2

SHGC roof: 0.2

UDI*: 82%

Adaptive comfort: 39/80 hrs
CONCLUSIONS
Is this process meant to be for **Architects** or **Engineers**?
FEEDBACK FROM ARCHITECTURAL AND ENGINEERING FIRMS

ARUP

UNSTUDIO
FEEDBACK FROM ARCHITECTURAL AND ENGINEERING FIRMS

**ARUP**
- It helps in taking informed design decisions from day One
- Visual approach for discussion with designers

**UNSTUDIO**
- Useful for defining early design decisions, (massing and amount of openings)
- Possible of application on larger number of masses

**FEEDBACK FROM ARCHITECTURAL AND ENGINEERING FIRMS**
CONCLUSIONS

Design intention and decisions have a big role in the future performances of a building.

Design variables and constraints play a key role for optimization potential.

Embedding natural ventilation early in the design process can lead to different morphologies and better overall results.

Better performances can be achieved by using an integrated approach, comprising also elements of the envelope.

Depending on the project, the use of specific design variables might NOT lead to any better result.
FURTHER DEVELOPMENT

Implementation of active aspects, (e.g. Energy production on site, mechanical installations design)

Inclusion of usage patterns for active systems

Better estimation of operational energy (starting with including artificial lighting)
Thank you!