EVALUATION AND PARAMETRIC OPTIMIZATION OF THE HEATING LOAD AND COMFORT CONDITIONS IN A SCHOOL BUILDING

Ricardo Almeida and Vasco Peixoto de Freitas

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THE LFC RESEARCH PROJECT
THE LBP RESEARCH PROJECT - Introduction

A MAJOR PROGRAM OF REFURBISHMENT OF SCHOOL BUILDINGS IS RUNNING IN PORTUGAL

INCREASE THE ENERGY EFFICIENCY OF THE BUILDINGS

IMPROVE THE INDOOR LEARNING ENVIRONMENT IN TERMS OF THERMAL COMFORT AND INDOOR AIR QUALITY
Assess the indoor environmental quality

Measurement of:
- Air Temperature [°C]
- Relative Humidity [%]
- Carbon Dioxide Concentration [ppm]

Optimization of constructive solutions to be used in the rehabilitation of school buildings

Objectives:
- Thermal Comfort
- Indoor Air Quality
- Economic Sustainability
THE LBP RESEARCH PROJECT

MULTI-OBJECTIVE OPTIMIZATION WITH CONFLICTING OBJECTIVES

ENERGY

DURABILITY

COMFORT

ECONOMIC
THE LBP RESEARCH PROJECT

CONSTRUCTIVE SOLUTION

BUILDING SIMULATION

OPTIMIZATION
THE LBP RESEARCH PROJECT

CONSTRUCTIVE SOLUTION

ARTIFICIAL NEURAL NETWORKS

OPTIMIZATION
METHODOLOGY
METHODOLOGY - Model

- No insulation
- Single glass
- No heating system
- Natural ventilation (window opening)
## METHODOLOGY - Model

### INTERNAL GAINS

<table>
<thead>
<tr>
<th>Zones</th>
<th>Metabolic rate [W/person]</th>
<th>Density [people/m²]</th>
<th>Occupancy profile (Monday to Friday)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom</td>
<td>94</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Circulation</td>
<td>112</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td>112</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Toilet</td>
<td>112</td>
<td>0.60</td>
<td></td>
</tr>
</tbody>
</table>

### CONSTRUCTION

- **U_{walls}** [W/(m²·°C)]: 0.96
- **U_{roof}** [W/(m²·°C)]: 2.51
- **U_{window}** [W/(m²·°C)]: 6.10
- **G_{window}** [-]: 0.81
- **ACR** [h⁻¹]: 0.25

- Annual simulations
- Hourly Outputs
- Model validation
  (Almeida and Freitas, 2010)
METHODOLOGY - Model

LOCATIONS

![Graph showing temperature and relative humidity trends for different locations.]

- Temperature [°C]
- Relative Humidity [%]

Locations:
- LOCATION A
- LOCATION B
- LOCATION C
METHODOLOGY - Variables and performance functions
METHODOLOGY - Variables and performance functions

VARIABLES

<table>
<thead>
<tr>
<th></th>
<th>(U_{\text{walls}}) [W/(m(^2).K)]</th>
<th>(U_{\text{roof}}) [W/(m(^2).K)]</th>
<th>(U_{\text{window}}) [W/(m(^2).K)]</th>
<th>(G_{\text{window}}) [-]</th>
<th>ACR [h(^{-1})]</th>
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<tbody>
<tr>
<td>Actual</td>
<td>0,96</td>
<td>2,51</td>
<td>6,10</td>
<td>0,81</td>
<td>0,25</td>
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<tr>
<td>Maximum</td>
<td>1,80</td>
<td>3,00</td>
<td>6,10</td>
<td>0,90</td>
<td>5,00</td>
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<tr>
<td>Minimum</td>
<td>0,25</td>
<td>0,25</td>
<td>1,00</td>
<td>0,20</td>
<td>0,10</td>
</tr>
</tbody>
</table>

PERFORMANCE FUNCTIONS

\[ f_1(U_{\text{wall}}, U_{\text{roof}}, U_{\text{window}}, G_{\text{window}}, \text{ACR}) = \frac{\sum \text{H.L.}}{S} \land T_{\text{int}} \geq 20^\circ C \]

Where:
- \(\text{H.L.}\) - hourly heating load (kWh)
- \(S\) - net floor area of the building (m\(^2\))
- \(T_{\text{int}}\) - hourly average interior temperature (°C)

\[ f_2(U_{\text{wall}}, U_{\text{roof}}, U_{\text{window}}, G_{\text{window}}, \text{ACR}) = \frac{\sum (T_{\text{int}} - 25)}{S} \land T_{\text{int}} > 25^\circ C \]
METHODOLOGY - Artificial Neural Networks (ANN)

1920 ANNUAL SIMULATIONS 160 FOR EACH LOCATION AND ORIENTATION

- 150 for training
- 10 for validation

COMBINATIONS

LOCATION  ORIENTATION  FLOOR  FUNCTIONS

A  NORTH  E  SOUTH  WEST
B  EAST  GROUND FLOOR
C  FIRST FLOOR  f1
  f2
METHODOLOGY - Artificial Neural Networks (ANN)

ARCHITECTURE

- Multilayer feedforward with backpropagation
- 20 neuron, 5 input, 1 output
- Training algorithm: Levenberg-Marquardt with Bayesian regulation
METHODOLOGY - Artificial Neural Networks (ANN)

VALIDATION

\[ R^2 = 1 - \frac{\sum_{i=1}^{10} (y_i - p_i)^2}{\sum_{i=1}^{10} (y_i - \bar{y})^2} \]

<table>
<thead>
<tr>
<th></th>
<th>LOCATION A</th>
<th>LOCATION B</th>
<th>LOCATION C</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>N</td>
<td>f_1</td>
<td>f_2</td>
<td>f_1</td>
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<tr>
<td>GF</td>
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<td>0.9727</td>
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</tr>
<tr>
<td>1st F</td>
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<td>0.9969</td>
</tr>
<tr>
<td>E</td>
<td>GF</td>
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<td>0.9766</td>
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<tr>
<td>1st F</td>
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<td>0.9840</td>
<td>0.9969</td>
</tr>
<tr>
<td>S</td>
<td>GF</td>
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<td>0.9323</td>
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<tr>
<td>1st F</td>
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<tr>
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<tr>
<td>1st F</td>
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<td>0.9866</td>
<td>0.9966</td>
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<td>MEAN VALUES</td>
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<tr>
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<td>0.9874</td>
<td>0.9879</td>
<td>0.9849</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION
RESULTS AND DISCUSSION - Evaluation of the school building performance

$f_1$ - Energy (heating load)

- Heating load higher in the first floor
- Heat losses through the roof are significant
RESULTS AND DISCUSSION - Evaluation of the school building performance

\[ f_2 \] - Comfort (overheating)

- Overheating is irrelevant on the ground floor
RESULTS AND DISCUSSION - Evaluation of the school building performance

Orientation

Differences due to orientation
- Less energy required when facing South
- Less overheating when facing North

Mean difference 9.5%
Mean difference 6.4%
RESULTS AND DISCUSSION - Parametric optimization

IT WAS EVALUATED THE IMPACT OF EACH VARIABLE IN THE ALL BUILDING PERFORMANCE

Roof thermal coefficient

- Varying the insulation of the roof could decrease the heating load from 73%, in location B, to 50%, in location C
- In locations A and C this change also improve the summer comfort conditions of the building
RESULTS AND DISCUSSION - Parametric optimization

Wall thermal coefficient

- Wall insulation could guarantee a **reduction of up to 45%** in the heating load
- But will be responsible for a **decrease in the summer comfort conditions**
RESULTS AND DISCUSSION - Parametric optimization

Window thermal coefficient and total solar energy transmittance

- Changes in windows are the most ineffective ones
- Although being possible to achieve a reduction of up to 30% in the heating load but the overheating problem will be intensified
A value of 4.0 h\(^{-1}\) in the ACR, minimum necessary according to the Portuguese legislation, implies an increase on the heating load that goes from 310\%, in location C, to 640\%, in location B.

Nevertheless the same change would decrease the overheating problem in 48\%, in location B, and 80\%, in location A.
CONCLUSIONS AND FUTURE WORKS
ANN are a good instrument to estimate complex functions and can be used to substitute computer simulations, even though they require a significant amount of input data for training in order to achieve accurate approximations.

Annual building simulation of complex models is a very time consuming procedure but necessary to understand the overall performance of the buildings.
CONCLUSIONS

MAIN CONCLUSIONS OF THE WORK

The orientation of the building is responsible for significant changes in its performance.

The most effective retrofit measure to decrease the heating load is the roof insulation.

The ACR is the most important variable in the performance of the building.
FUTURE WORKS

OPTIMIZATION OF CONSTRUCTIVE SOLUTIONS

MULTI-OBJECTIVE OPTIMIZATION USING EVOLUTIONARY ALGORITHMS

LIFE CYCLE ANALYSIS OF THE SOLUTIONS
THANK YOU FOR YOUR ATTENTION