Energy conscious automated design of building façades using genetic algorithms

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Various European Directives have been issued concerning the energy efficiency of the buildings. The target is the achievement of a near optimum energy efficient environment while at the same time satisfying occupant needs throughout the year within an integrated “holistic” or “whole building” framework. A variety of different antagonistic parameters should be balanced such as window size and glazing transmittance or daylighting and shading and in most cases this requires an examination of various scenarios. Thus the design of building envelopes should address a careful balance between internal requirements and loads, the materials and properties of the façade and the external environment. Nowadays, the available tools for façade design—in terms of building’s energy efficiency—are inappropriate for interactive or creative use.

In this paper we examine the development of a genetic algorithm which is capable to optimise the opening areas, glazing properties and shading configurations—on the basis of minimum energy consumption—and then to design automatically simplistic alternative scenarios of the building façade.

Keywords: Genetic algorithms; building energy efficiency

Introduction

Today’s growing concern of energy usage in buildings has lead to a huge interest in alternative energy production and most of all, energy conservation. Thus, the design of facades in commercial buildings and the associated heat transfer though is quite crucial for the energy performance of the whole building. However techniques to reduce possible “energy penalties” can be quite costly, therefore it is extremely important to accurately calculate the energy impact of these techniques.

In Europe, buildings represent almost 40% of its global energy consumption. The use of passive solar techniques can contribute to reduce significantly the total energy consumption. These techniques, aiming at increasing direct gains and daylight during the winter period, should make use of shading devices or window size to avoid overheating during the summer period while at the same time daylighting levels should be maintained. This can be quite tedious, since various—and very often contradictory—parameters should be balanced.

Although the use of building energy simulation
tools (e.g. ESP-r Clarke, 2001 TRNSYS\(^1\), TAS\(^2\), DOE-2\(^3\), etc.) can be used to optimise the façade design in energy terms, such an approach can be quite expensive and time consuming as well. Thus estimation of glazing size-properties and shading can significantly improve if some kind of numerical optimisation is used.

Such an approach has already been investigated and optimisation codes using the above mentioned simulation engines are available (GENOPT, Wetter, 2001). One of the main disadvantages is the complexity of the interface. Practical methods to estimate the ideal window size (Backer et al, 1988) or the design of shading device have been developed but information, these tools offer to the designer, is not very useful, and in extreme cases it is sometimes even inaccurate and misleading. The lack of simplified evaluation tool, capable on providing information on the suitability of a window size and its potential to save energy, is considered as one major reason for the reluctance of building professionals in incorporating some kind of energy optimisation in their design. It is the belief that significant benefits are available in introducing an optimisation scheme at the earliest design stages leading to improved design entities.

**Method**

The design problem concerns the estimation of window size, glazing thermal and optical properties and shading factor for a building’s typical office module.

The tools that have been used for the estimation of its energy consumption was Summer –Building a tool that uses Balance Point Temperature to estimate monthly heating and cooling loads (Santamouris et al, 1995). The simplest method to predict energy savings due to daylight is to assign a single annual figure for lighting energy use. This is accomplished by estimating a cumulative frequency distribution of illuminances for a point (or on average) in the interior. This is difficult to be performed on hourly basis for the typical meteorological year. Thus a more simplified procedure is followed, using a monthly cumulative frequency distribution of the exterior horizontal illuminances. By multiplying with the average daylight factor (BRE Digest 309, 1986), interior cumulative frequency distribution can be estimated. Although the method is simple, the multiplication implies that the sky is considered as overcast all year long thus the result somehow represents a worst-case scenario. Of course sunlight is excluded.

These tools can be used as a pre-design tool to assess the potential of the design, avoiding lengthy input process and time-consuming calculation.

The building is a middle-size office building with office modules aligned on two façades, separated by a central corridor, with staircase/service spaces at both ends of the building.

Dimensions and the data that were used are given in the next tables and figures. The windows are located on the south façade of the building. The optical properties of the elements inside the office room are presented in Table 1.

Since the specification (in our case room dimensions and walls thermal and optical properties) have

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3. Widely used and accepted building energy analysis program, [http://www.doe2.com/](http://www.doe2.com/)
been set, the energy consumption for heating, cooling lighting is evaluated. If this specification is not satisfied, the initial design is modified and re-evaluated. The whole procedure is repeated until the design fulfils the initial demands. This is more or less a trail & error method and despite its simplicity, processing time can be huge since all possible variations have to be examined.

A better methodology is to use a genetic algorithm approach (Davis, 1991). Genetic algorithms are search algorithms based on the mechanics of natural selection and are very well suited to solving problems involving very large search spaces. Each possible solution to the design problem is encoded as a string of numbers which is called a chromosome. Each chromosome is consists of a number of genes which represent the design parameters. In this paper the genetic algorithm (GA) that have been used is an implementation of the simple GA described by Goldberg (1989).

**Implementation of the GA**
Table 2 presents the design parameters, their lower and upper bound and their step size used in the optimisation.

These variables are included in the design representation are those that give all the required information so that the performance of the specific façade design. Since daylighting is taken into account visible transmittance is also required and this could –in principle- included in the design parameters. However solar and visible transmittance are not independed variables. Thus it was decided that only solar transmittance should be used and then by using solar transmittance and U-value a glazing type is selected through a list of 20 glazing types and hence the visible transmittance.

The fitness function which measures the quality of the performance of a solution and which the GA is trying to maximize is defined as follows:

\[
FF = \frac{1}{a \cdot CL + b \cdot HL + c \cdot LL}
\]

Where CL, HL and LL are the annual cooling, heating and lighting load respectively (KWh/m²). These loads should be modified in order to take into account heating and cooling system efficiencies and the associated cost and this is performed through the use of the parameters a, b and c. Since these parameters can affect the fitness function, the relative difference in oil (for heating) and electricity (for cooling and lighting) prices can also affect the final solution. The choice of population size, probability of mutation and crossover is depended on the characteristics of the optimisation problem. For these kind of problems bibliography suggests population sizes to range from 5 to 100, crossover probability from 0.3 to 1 and the mutation probability from 0.001 to 0.05 (Wetter et al, 2003).

**Results**
Genetic algorithms are stochastic processes and tend to be sensitive in the quality of the initial –randomly produced-population. Several runs of the genetic algorithm were performed while the evolution of the best (maximum) individual (best fitness function) and the entire population (average fitness value) were recorded. Some results are presented below.

Average population values for the parameters that affect the fitness function are presented in the figure 4. while Figure 5 shows the evolution of heating, cooling and lighting specific consumption (kWh/m²).

<table>
<thead>
<tr>
<th>Elements of the room</th>
<th>Reflectance</th>
<th>Transmittance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling</td>
<td>0.75</td>
<td>-</td>
</tr>
<tr>
<td>Walls</td>
<td>0.50</td>
<td>-</td>
</tr>
<tr>
<td>Floor</td>
<td>0.30</td>
<td>-</td>
</tr>
<tr>
<td>Door</td>
<td>0.40</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Optical properties of the elements inside the office module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window Length</td>
<td>Upper bound</td>
</tr>
<tr>
<td>Window length</td>
<td>0.1</td>
</tr>
<tr>
<td>Window height</td>
<td>0.1</td>
</tr>
<tr>
<td>Glazing Solar Transmittance</td>
<td>0.1</td>
</tr>
<tr>
<td>Glazing U-value</td>
<td>2</td>
</tr>
<tr>
<td>Overhang Width</td>
<td>0</td>
</tr>
</tbody>
</table>

| Table 2 | Lower, upper bound and step size of the design parameters. |
After the tuning of the GA the results were passed to RADIANCE for the visualization of the façade. This is presented in Figure 6.

Conclusions

The paper demonstrated how genetic algorithms combined with simplistic calculation tools for estimating energy consumption can be applied to the
initial phase design of a building’s façade by estimating:

- Window thermal and optical properties
- Window size
- Shading

Trial and error design approaches become less useful as the design complexity increases thus a more generalized method is needed. Genetic algorithms as “search engines” can cover quickly and effectively the design space offering a family of design solutions that fulfils the design criteria.

References


