

GENETIC OPTIMIZATION OF EXTERNAL SHADING DEVICES

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ABSTRACT

A genetic optimization approach has been used for the design of an external shading device in an office with a window and different glass characteristics. The primary energy consumption for heating cooling and lighting have been minimized. Simulations have been performed using the energy code ESP-r and lighting simulation package Radiance, the optimization loop has been driven by the software tool modeFRONTIER. Different optimal geometries for a panel shading device have been found.

INTRODUCTION

The constant increase in summer energy consumption due to building climatization is becoming a major concern for industrialized countries. Therefore energy saving strategies must be sought in order to guarantee both healthy conditions and low environmental impact. This is true especially for buildings with extensive glazed areas in Mediterranean area where high cooling loads are due because of solar irradiance.

In Italy, for example, national codes require the compulsory installation of external shading devices for buildings with total surface area greater than one thousand square meters, but the choice of the external shading devices is left to the designer and no guidelines are yet available.

The size and positioning of shading devices depend on the orientation of building facade, the size of the windows and the relative importance of heating and cooling loads. Furthermore external shading devices have an impact also on the internal daylight distribution. The architectural impact must also be taken into account by inserting shading surfaces as little as possible without jeopardizing energy savings.

In designing an external shading device hence all the energetic, daylighting and architectural problems must be taken into account at the same time.

In this paper the multiple aspects of the problem have been coped with using genetic optimization techniques. The software tool ESP-r, (Clarke 2001) has been utilized for computing thermal loads, Radiance (Radiance 2008) for computing daylight factors while the optimization has been driven by modeFRONTIER (modeFRONTIER 2008).

In literature can be found a number of papers who deal with the problem of the impact of shading devices on energy consumption, nevertheless they usually consider separately climatization and light analysis problems.

A detailed comparison of solar gain models with external and internal shading screens have been presented in Loutzenhiser et al, 2007. Different codes have been compared, among them the ESP-r tool used in this paper, the authors found that accurate results can be achieved when predicting the energy consumption for long period of time for highly glazed buildings.

An insight on the coupling between daylight and thermal loads has been conducted in Franzetti et al, 2004, 14 parameters have been identified and the computations have been performed using “the experience plan” method with the aim of reducing the number of simulations. Different relations linking the most important parameters with lighting energy consumption and annual energy needs have been elaborated. It has been found that an efficient lighting control device has a favorable impact on global energy needs emphasizing the importance of taking into account the interaction between lighting and HVAC system. Li et al. 2008, studied the effect of daylighting and energy use in heavily obstructed residential buildings in Honk Kong, they simulated the daylighting performance of high rise buildings varying five parameters for assessing daylight availability, they found limits for external obstructions in order to reach satisfactory internal levels of daylighting.

Ho et al 2008 analyzed daylight illumination of a subtropical classroom, seeking an optimal geometry for shading devices, they also evaluated the lighting power required to improve the illuminance condition within the classroom.

Gugliermetti et al. 2006 used the solar system luminous efficacies method to compute indoor natural illuminance. They introduced three simplified approaches for dealing with the effect of horizontal and vertical shading devices, comparing the obtained results with experimental data. They also included the developed methods in a building energy simulation code to compare the impact of the

different methods on the heating, cooling and lighting requirements of an office building.

Optimization techniques applied to building analysis is emerging as an interesting tool for designers and accordingly a number of applications are available in literature.

Diakaki et al. 2008 used multi-objective optimization for improving energy efficiency in buildings, for this aim they proposed decision criteria based on simplifying assumption on energy calculation, furthermore they used utility functions to reduce the decision model to one only criterion. Nevertheless they highlighted that optimization is an helpful tool for reducing energy costs.

Genetic algorithms have been used in Znouda et al. 2005 to tackle the problem of design of buildings in Mediterranean area, they highlighted that the finding of best characteristics of a building for summer and winter seasons is always a trade off among conflicting options. Very interestingly they discovered that the solution for saving energy and saving money are quite different. Manzan et al. 2006 applied Multiobjective Genetic Optimization (MOGA) for assessing energy savings in office buildings with night ventilation, the objectives of the optimization where the minimization of energy consumption and the percentage of dissatisfaction inside the building. A Generalized Pattern Search has been developed in Wetter and Polak 2005 to minimize the annual source energy in a house taking into account heating cooling and lighting, the main effort of the authors were devoted to the evaluation of a simulation-precision control algorithm to speedup the overall time for the computation.

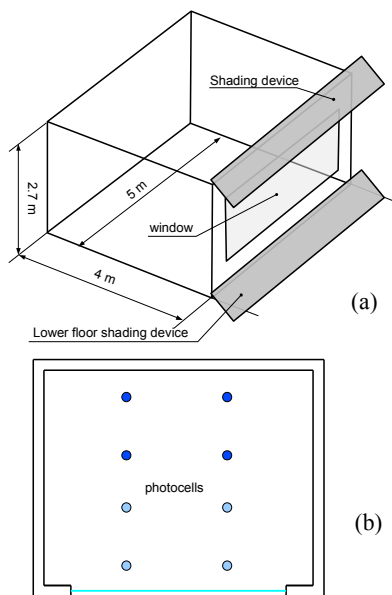


Figure 1 a) office with shading device b) position of photocells for light gain control

SIMULATIONS

Problem description

Shading efficiency is strongly affected by the size and position of shading devices. In the present paper a Genetic Optimization (GO) has been carried on an office room with a roof surface of 20 square meters and a south facing window 4 m wide and 1.5 m high. The office, to be considered at the first floor of a multi-storey, building is 2.7 m high, 5m wide and 4 m deep. Figure 1 (a) reports the geometry of the room with the shading device. External wall have a thermal transmittance of $0.32 \text{ W}/(\text{m}^2 \text{ K})$. Two different glazing systems have been taken into account, one standard double glass and an high performance glazing system specifically designed to prevent high sun loads. The characteristics of the considered glazing systems are reported in Table 1.

Table 1
glazing systems characteristics

	g	T	U
	-	-	$\text{W}/(\text{m}^2 \text{ k})$
standard	0.522	0.792	1.4
High performance	0.234	0.538	1.4

For south facing windows an effective solar control can be naturally obtained by window reveals, hence this geometrical feature is expected to have a direct impact on the optimal geometry of shading device. In this study the effect of a 0.20 m reveal has also been considered. The mix of geometry and window characteristics gives rise to a set of six cases to be investigated as listed in Table 2, a reference case of window without reveal and shading panel has been added as well.

Table 2
The cases investigated

DESCRIPTION	CASE
Standard glass without reveal	1.1
Standard glass with reveal	1.2
Standard glass without panel	1.1.0
High performance glass without reveal	2.1
High performance glass with reveal	2.2
High performance glass without panel	2.1.0

Internal loads and occupancy schedules conform to EN ISO 13790 and are reported in Table 3 for Weekdays, on Saturday and Sunday an equipment load of $2 \text{ W}/\text{m}^2$ has been inserted. The ventilation and leakage rate during workday is 3 ach, while on Saturday and Sunday only a 0.3 ach due to air infiltration is considered

Table 3
Weekday distribution of thermal gains

	0am–7am W/m ²	7am–6pm W/m ²	6pm–12pm W/m ²
equipment	2	15	2
persons	0	7.5	0
light	0	15	0

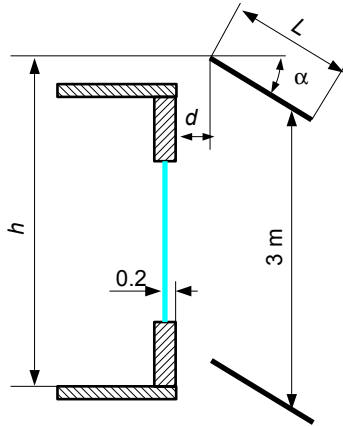


Figure 2 Input parameters used for the optimization

Shading device

The shading device is a flat panel positioned parallel to the window and inclined by its horizontal axis as presented in Figure 1 a). The device shades the window from direct sun penetration reducing the cooling loads in summer, but also affecting daylight and heat loads in winter limiting the sun gains, therefore the impact on the overall building energy consumption is investigated. A genetic optimization has been performed for identifying a possible geometry with the lower energy cost impact. The optimization is performed modifying the geometrical variables highlighted in Figure 2 for a total of four parameters: shading height, width, angle and distance from the wall.

Computer simulation approach

The ESP-r code has been used for energy simulation. The code performs shadowing analysis using prismatic blocks as obstructions that can be used to simulate other buildings, horizontal overhang, vertical fins, windows sills and reveals. Unfortunately obstruction can only be rotated along vertical axis. The source code of ESP-r has been therefore modified to represent inclined flat panels too.

The ESP-r system is a collection of software tools that interact to perform the building simulation. The computation is performed by the *bps* tool, while shading information is read at runtime from a shading database previously generated by shading analysis module *ish*. The modified code has been

successfully tested against the original *ish* module by running cases with thin 3d prismatic blocks at inclination $\alpha = 0^\circ$ and 90° respectively.

The input parameters of the new obstruction object, are the three coordinates of the up left corner of the device, the length, the inclination angle by horizontal axis α and the rotation angle along the vertical one. The inclination angle has been taken positive as presented in Figure 2, it is worth noting that input coordinate system for the device is different from the one used for 3d block obstruction.

Daylight simulation

The ESP-r code can cope with daylighting simulations, for instance it incorporates different coupling methods. It is possible to compute horizontal workplane daylight factors by combining analytical formula for sky component and split flux method for interreflected component, alternatively a user defined daylight factor can be defined. More computing demanding methods are present as well: a full coupling method in which the lighting simulations is performed with Radiance at each time step and a daylight coefficients method where a set of daylight coefficients are precomputed using Radiance (Clarke 2001).

For this work a different approach has been adopted. Since the simulation has to be inserted into a optimization loop and a great number of simulations should be performed the last two methods have been discarded. Therefore the user defined daylight factors method has been selected, while the factors at the beginning of each simulation and with a defined shading device geometry are computed using Radiance. The computed daylight factors are then inserted into the input control gain file to drive the artificial lighting operation.

Energy gains resulting from the switching of internal lights has been taken into account in a simplified way: the office has been subdivided in two zones, one near the window, the other far from it, as illustrated in Figure 1 (b) four illuminance sensors for each zone control the artificial lighting switching. The illuminance switch on level for internal luminaries has been set to 300 lux while switch off set point has been set to 450 lux. Each sensor group drives half the lighting power of the internal room.

For daylight factor computation the reflectance of internal wall, floor and ceiling have been taken as 0.6, 0.3 and 0.7 respectively.

Optimization

The word optimization can be explained as the task of obtaining the best configuration for a system with a defined number of degrees of freedom, and subjected to certain constraints, (Rao, 1996) both on inputs or outputs. The goal desired is the so called *objective function* that can be a single parameter O or a certain set O_1, O_2, \dots, O_m . The *objective* is function of

some other decisional parameters, i.e. X_1, X_2, \dots, X_n , called *design variables*.

Optimization algorithms can be divided into classical and evolutionary. Classical techniques are not able to deal with multi-objective optimizations, instead they use the so-called utility functions. Namely, with the use of some criteria (weighting operations) in order to combine the objectives, a unique functional is created and optimized as a single objective. On the other hand, evolutionary (probabilistic) algorithms allow maximizing a function without any restriction imposed by functional constraints, as gradient-based algorithms do. Moreover, they can perform truly multiobjective optimizations. An other problem in using classical deterministic optimization has been highlighted by Wetter and Wright 2004 which carried out a comparison of deterministic (classical) and probabilistic optimization algorithms on non-smooth optimizations underlining the difficulty in reaching a good solution with gradient based algorithms.

In our problem the solution is not continuous due to on-off control of luminaries, therefore an evolutionary algorithm has been selected. This choice will also allow for an easily transition towards a future true multiobjective approach. An efficient version of the MOGA algorithm, MOGAI, available in modeFRONTIER has been used. The fundamental characteristics of MOGAI are the possibility to study multi-objective problems and the robustness in converging toward the optimal solution.

In this work a one objective formulation for the problem has been used, as in Wetter and Polak 2005 the objective to be minimized is the annual primary energy consumption defined as:

$$O(X) = \frac{Q_h}{\eta_h} + \frac{Q_c}{\eta_c} + \frac{Q_{el}}{\eta_{el}} \quad (1)$$

where the efficiencies are set as $\eta_h=0.8$, $\eta_c=0.8$ and $\eta_{el}=0.4$. It is worth noting that a different objective could be identified by introducing cost rates of each energy vector, but this approach could result in an objective heavily dependent on parameters difficult to control, as the prices of each energy vector are.

ModeFRONTIER tool

ModeFRONTIER is a general optimization tool, in the sense that it can drive an optimization loop using different applications. It allows to perform true multiobjective optimization and give the designer the option to select different optimization algorithms.

The setup of the problem is easily performed using the workflow designer. The logical sequence to be used during optimization is described by linking nodes representing input variables, constraints, calculation nodes, application nodes, output variables and objectives.

The workflow developed for the present work is presented in Figure 3.

The input variables are fed to the input nodes *radFile* and *obstacle*, the former writes the geometrical description of the shading device to be used by Radiance for calculating daylight factors, the latter writes the same geometry to an input file to be read by *ish* at the beginning of each calculation to generate the shading database. For daylighting analysis a second panel is inserted at 3 m below the upper one, as presented in Figure 2, to take into account reflected light and ground shading by the panels pertaining to the lower floor.

The computation of daylight factors is performed by the node *runRad* who triggers a shell script for running Radiance. The node *runDayFact* is responsible for reading the eight computed day factors highlighted in Figure 1 which are then transferred to the input node *setDayFact* which writes the factors into an input file to be used by ESP-r program *bps*.

The ESP-r computation can then be invoked by the shell script *compute* which generates the shading database, runs the computation and reads result files generating two output files. These file are read by the nodes *readGain* and *Conditioning* to retrieve annual cooling, heating and electricity consumption used by node *PrimaryEnergy* for computing, according to Equation 1, the objective function to be minimized.

The range of input parameters is presented in Table 4. The optimization is carried in two steps, first the input parameters are allowed to variate in a broad range, then when the range of optimal solution is identified the optimization is repeated using a finer discretization. Each optimization has been performed along 100 generations of 16 individual each.

Table 4: input variables and ranges

	STANDARD			FINE		
	min	max	step	min	max	step
<i>h</i>	2.8	3.5	0.05	2.8	3.5	0.03
<i>L</i>	0	2	0.05	1	2	0.01
<i>d</i>	0	1	0.05	0	1	0.03
α	-45	90	2.5	-15	45	1

Input parameters are not free since they have to satisfy constraints. It is not desirable to have an intrusive shading, therefore the following two constraints have been enforced:

$$d + L \cdot \cos(\alpha) \leq 2 \text{ m} \quad (2)$$

$$h - L \cdot \sin(\alpha) \geq 2.1 \text{ m} \quad (3)$$

the former constraint limits the horizontal protrusion of the panel, the latter avoids the view of people into the office to be obstructed by the shading device, the two constrains are imposed by nodes *maxExtern* and *minHeight* in Figure 3.

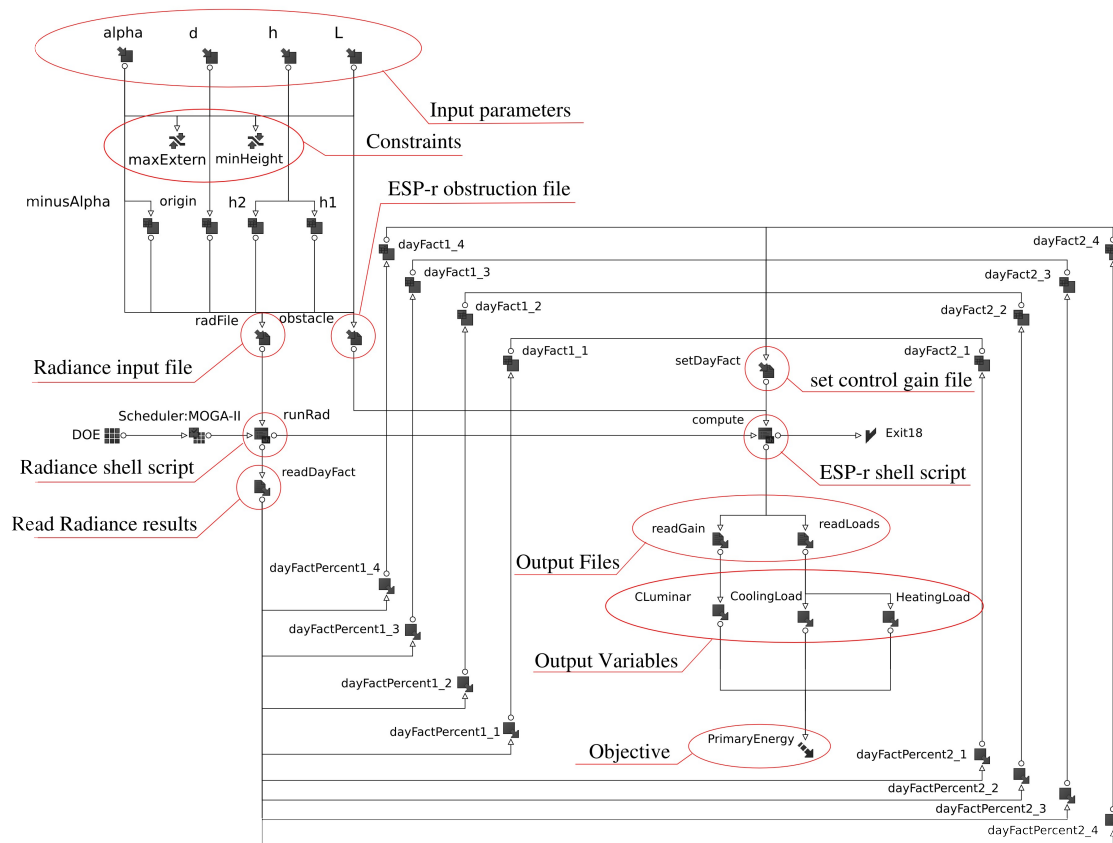


Figure 3 The workflow of modeFRONTIER,

DISCUSSION AND RESULT ANALYSIS

Figure 8 reports the history of the objective function for case 1.1, in abscissa and ordinate are reported the design identification number and the required primary energy respectively. Figure 9 reports instead the panel length for each evaluated design, and shows how the algorithm converges toward an optimal solution. Inspecting Figure 8 appears that near optimal solutions are found after few generations have been evaluated, since the solutions cluster near the 100 kWh/m² value. After design ID 1500 the optimization has been restarted with the finer discretization reported in Table 4, again the convergence is very quick and the minimum of objective function is attained in design ID 1998. The designs with higher values of Primary Energy in Figure 8 correspond always to solutions without shading device.

Table 5 reports all the numerical results of the optimization, the last column shows the percent reduction in primary energy with reference to a configuration without shading device. The mean values of daylight factors computed at the sensors of Figure 1 are also reported, DF_1 is the mean value computed by photocells near the window, while DF_2 is the value for the ones far from it.

An additional alternative solutions is also reported by selecting the minimum of the objective function

with a length of the shading device less or equal than 1 m, for case 1.1 such a solution is reported in Figures 8 and 9 as design ID 1624. These solutions are identified in Table 5 by adding .1 to the respective case numbering. The identified optimal configurations are reported graphically for case 1 in Figure 4 and for case 2 in Figure 5.

At first glance it is clear that substantial reduction of energy consumption is obtained with a wider shading device. For both solutions rather horizontal panel is selected by the optimizer, however if shorter panel size is forced, an higher inclination angle is sought. The data of Table 5 is reported graphically in Figure 6 for case 1 and Figure 7 for case 2.

For case 2 the optimal size of the panel is always shorter than that of the corresponding case 1 and the reduction of energy requirement is substantially lower. This result is due to the already strong shading characteristics of the high performance window of case 2, so the savings in summer cooling consumption are jeopardized by winter heating and lighting consumptions increase.

The reduction of panel size affects both cases, but in particular mode case 1 where the optimum width is greater. Nevertheless also in this case the primary energy reaches a 14 percent reduction for case 1.2.1.

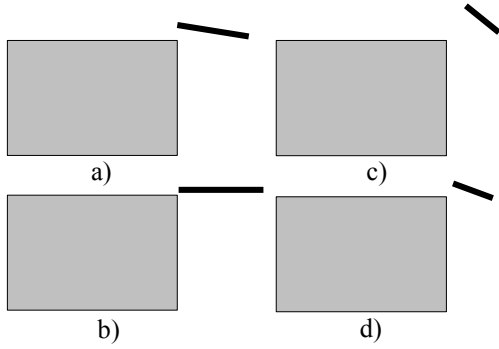


Figure 4: case 1 shading geometry for cases a) 1.2, b) 1.1, c) 1.2.1, d) 1.1.1

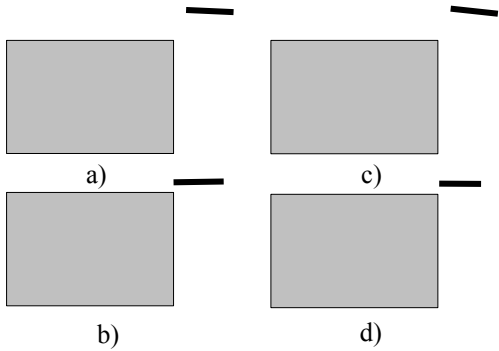


Figure 5: case 1 shading geometry for cases a) 2.2, b) 2.1, c) 2.2.1, d) 2.1.1

CONCLUSION

A genetic optimization of an external shading device has been performed for minimizing the overall primary energy in an office room. The energy consumption for cooling, heating and internal illumination has been taken into account. The optimizer modeFRONTIER has been coupled with the software Radiance for daylight factor calculation and with ESP-r code for building energy simulation. The coupling of shading device with different glazing systems have been analysed. For each configuration a different solution is obtained with a reduction of

primary energy consumption of up to 17 %. The obtained solutions demonstrate how genetic optimization can be a powerful tool for the designer. The results showed that the impact of shading devices on buildings energy has always to take into account the electrical energy absorbed by the lighting system.

Future work should take into account other parameters not introduced in this paper, such as glare discomfort indices, a direct simulation of the illuminance levels inside the room, and smarter control of luminaries.

NOMENCLATURE

d	distance from wall (m)
DF	daylight factor
g	solar factor
h	height of panel (m)
L	width of shading panel (m)
O	objective for optimization
Q_c	cooling energy requirement (kWh)
Q_{el}	lighting energy requirement (kWh)
Q_h	heating energy requirement (kWh)
Q_p	primary energy (kWh)
T	glass visible transmittance
U	glass transmittance ($W/m^2 K$)
X	variable for optimization

Greek

α	panel horizontal inclination angle (deg)
η_c	cooling efficiency
η_h	heating efficiency
η_{el}	electrical efficiency

Subscripts

c	cooling
h	heating
el	electricity
$c+h$	cooling + heating
p	primary

Table 5: Results of optimization for different cases

	h	α	d	L	Q_{el}	Q_c	Q_h	DF_1	DF_2	Q_p	%
	m	deg	m	m	kWh/m ²	kWh/m ²	kWh/m ²			kWh/m ²	
1.2	3.06	9	0.11	1.7	15.21	33.62	15.91	5.81	1.57	99.95	16,60
1.1	2.82	0	0.03	2	14.17	35.7	15.54	6.45	1.75	99.45	17,02
1.2.1	3.2	38.7	0.35	1	14.9	37.29	14.95	6.38	1.59	102.55	14,43
1.1.1	2.84	20	0.13	1	13.73	41.61	14.12	7.39	1.81	103.95	13,27
1.1.0	-	-	-	-	14.2	54.8	12.84	8.91	1.64	119.85	0
2.2	3.4	2.5	0.3	1.14	26.35	34.87	16.38	5.2	1.1	129.9	4.2
2.1	2.95	-1	0	1.2	23.63	35.03	16.02	5.5	1.29	122.9	9.37
2.2.1	3.35	6	0.25	1	26.29	35.28	16.38	5.31	1.1	130.3	3.91
2.1.1	2.95	0.5	0.03	1	23.5	36.3	15.84	5.8	1.29	123.9	8.63
2.1.0	-	-	-	-	23.09	47.56	14.75	7.17	1.26	135.6	0

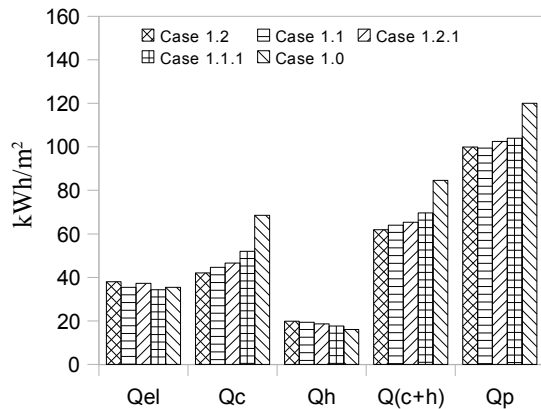


Figure 6: Case 1, primary energy required

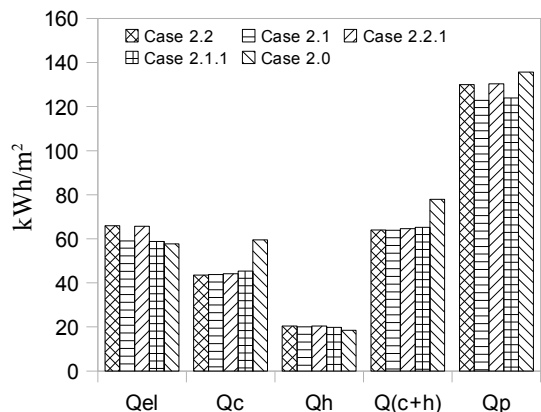


Figure 7: Case 2, primary energy required

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REFERENCES

Clarke J. A. 2001, Energy Simulation in Building Design, Butterworth Heinmann, Oxford, GB

Diakaki Christina, Grigoroudis Evangelos, Kolokotsa Dionyssia, 2008, Towards a multi-objective optimization approach for improving energy efficiency in buildings, Energy and Buildings 40, 1747–1754

ESP-r Software (Version 11.5), 2008, Building Energy Simulation Code, University of Strathclyde, Glasgow, available from: <http://www.esru.strath.ac.uk/Programs/ESP-r.htm>

Franzetti C., Fraisse G., Achard G., 2004, Influence of the coupling between daylight and artificial lighting on thermal loads in office buildings, Energy and Buildings, 36, 117-126

Gugliermetti F., Bisegna F., 2006, Daylighting with external shading devices: design and simulation algorithms, Building and Environment, 41, 136-149.

Ho M.C., Chiang C.M., Chou P.C., Chang K.F., Lee C.Y., 2008, Optimal sun-shading design for enhanced daylight illumination of subtropical classrooms, Energy and Buildings 40, 1844–1855

Li D.H.W., Wong S.L., Tsang C.L., Gary H.W. Cheung, 2004, A study of the daylighting performance and energy use in heavily obstructed residential buildings via computer simulation techniques, Energy and Buildings, 36, 117-126

Loutzenhiser P.G., Manz H., Felsmann C., Strachan P.A., Maxwell G.M., 2007, An empirical validation of modeling solar gain through a glazing unit with external and internal shadingscreens, Applied Thermal Engineering, 27, 528-538

Manzan M., Pinto F., Saro O., 2006, Thermal Comfort and Energy Saving Optimization for HVAC Systems with Night Ventilation Cooling, Healthy buildings 2006, Lisboa, June 4-8 2006, V 175-180.

modeFRONTIER 2008, version 4.1 Documentation. <http://www.esteco.com>

RADIANCE 2008, version 3.9, available at <http://radsite.lbl.gov/radiance>

Rao S., 1996 Engineering Optimization, Theory and Practice, John Wiley & Sons, Inc., New York

Standard EN ISO 13790, 2008, Energy Performance of Buildings, Calculation of Energy Use for Space Heating and Cooling

Wetter M., Polak E. 2005. Building design optimization using a convergent pattern search algorithm with adaptive precision simulations, Energy and Buildings 37,603–612

Wetter M., Wright J. 2004. A comparison of deterministic and probabilistic optimization algorithms for non smooth simulation-based optimization, Building and Environment, 39, pp. 989-999.

Znouda E., Ghrab-Morcous N., Hadj-Alouane A., 2007, Optimization of Mediterranean building design using genetic algorithms, Energy and Buildings 39, 148–153

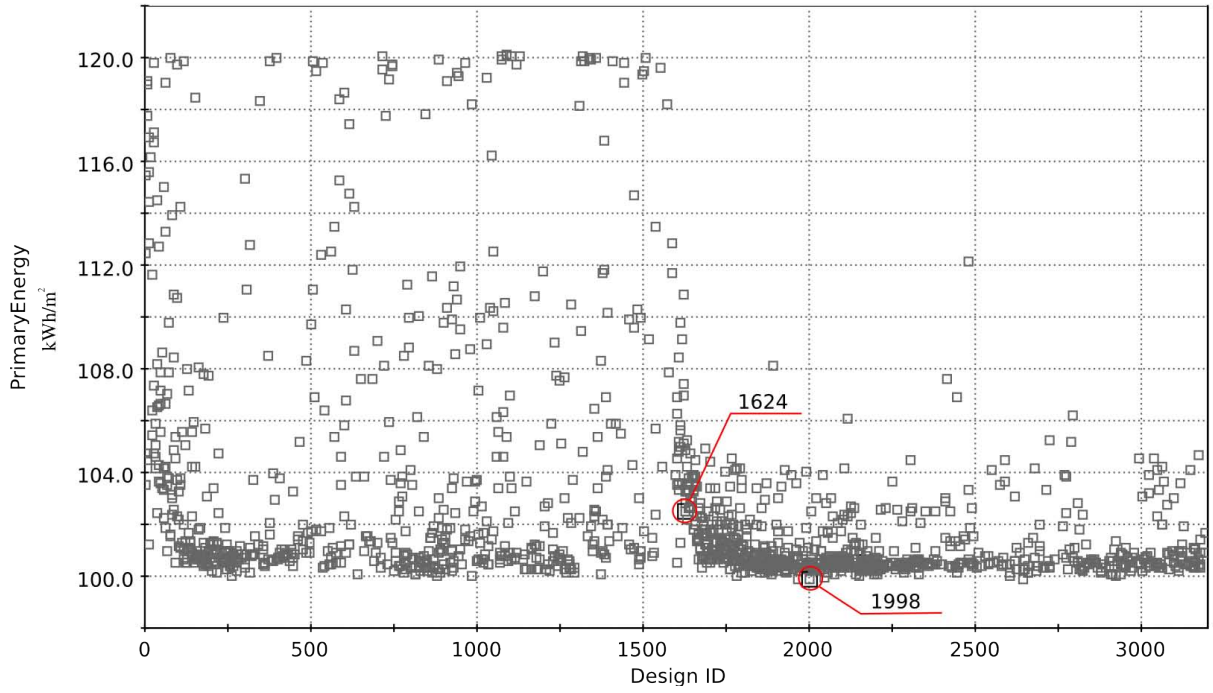


Figure 8: evolution of objective function during the optimization loop

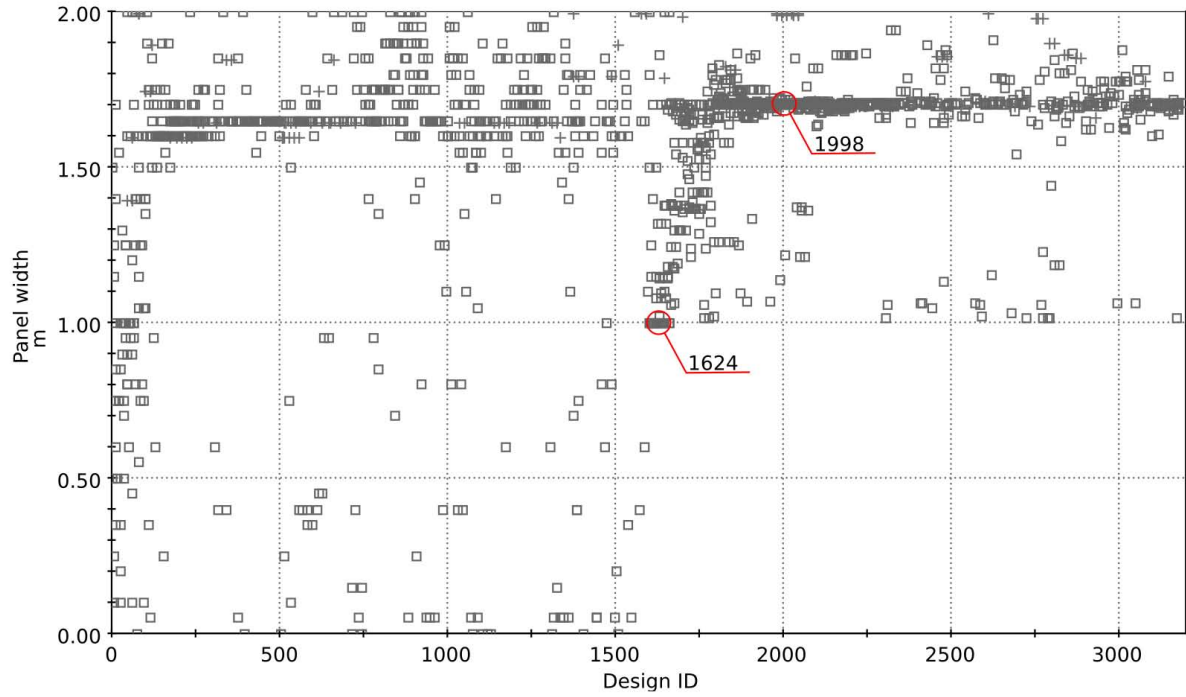


Figure 9: evolution and convergence of shading panel width during optimization