# Decision Support System for the Design of Office Buildings in Senegal

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## 1. INTRODUCTION

Decisions concerning the use of energy efficiency measures taken at the early design stage are crucial to reduce the environmental impact of the energy used in buildings. Energy efficiency measures should reduce i) the operating energy and energy embodied in building components, ii) the related environmental impacts and iii) the life-cycle cost of buildings. The possibilities of optimising the design of buildings on the basis of these criteria are numerous. Clearly, architects are in need of a tool to help them at the design stage to easily and quickly (this is essential) evaluate the performance of the various design alternatives they may consider. This paper reports on such a tool, packaged in the form of a computerised decision support system (DSS), which was developed for architects of Senegal.

The DSS is based on a four-part procedure: (1) definition of a generic reference building, (2) selection of design alternatives, (3) determination of the embodied and operating energy, the carbon dioxide emissions and the life-cycle cost associated with these alternatives, and (4) selection of the most appropriate measures using a multicriteria evaluation technique.

## 2. REFERENCE BUILDING

The reference eight-floor office building is situated in Dakar, the capital of Senegal. The building has a rectangular footprint, with a total floor area of about 1700 $m^2$. The ceiling height is 2.7 m. Walls are composed of 15 to 22 cm thick block walls, with clear glass windows. Dark-coloured drapes are used to protect the interior spaces from solar radiation. The window-to-wall ratio is 0.9. Floor slabs are made of 37 cm thick reinforced concrete.

In Dakar, monthly mean temperatures range from 20 to 28 °C, and monthly mean relative humidity, from 47 to 89 %. Internal conditions for cooling, 25 °C and 50 % RH, are maintained in the building through the use of window-type air-conditioning units. There is no heating system.

Fluorescent lamps, installed in suspended luminaires, are used whenever dayligthing is insufficient. The installed electric lighting load is 6 $W/m^2$. The interaction between artificial lighting and daylighting is manually managed.

## 3. DESIGN ALTERNATIVES

Several design alternatives are selected, with a particular focus on the building envelope. Seven parameters are considered : wall type (concrete panels or blocks), thickness of thermal insulation of the roof (0, 20, 40 mm), thickness of thermal insulation of the walls (0, 20, 40 mm), overhangs width (0, 60, 80, 100, 120 cm), windows-to-wall ratio (0.9, 0.8, 0.7, 0.6, 0.5), glazing type (clear, tinted, reflecting, double clear, double selective), and drapes colour (dark, light). The translation of these seven parameters into design alternatives leads to 4,500 combinations.

The reference building can be oriented along the four main orientations (east, north, west, south), and can be exposed to three different neighbourhood conditions, leading to twelve reference configurations. Hence, the total number of design alternatives reaches 54,000.

## 4. EVALUATION CRITERIA

The criteria for the evaluation of different design alternatives are energy consumption, carbon dioxide ($CO_2$) released, and costs, all being calculated on a life cycle basis. For each design alternative, the index of performance is calculated as the difference from the reference building, and reported for 1 $m^2$ of floor area. For example, the index of embodied energy is the embodied energy associated with a given design alternative minus the embodied energy of the reference building.

A process analysis was used to determine the energy contents and the $CO_2$ released in association with the production of the concerned materials, using data collected in Senegal (Ndiaye, 2001).

The energy consumption, $CO_2$ emissions and costs associated with the maintenance/renovation and demolition/recycling/disposal phases are not considered since these factors are assumed to be negligible in the case when the design alternatives concern only the building envelope.

The annual operating energy consumption and cost associated with each design alternative are determined by computer simulations using DOE-2 (Acrosoft, 1994). Since electricity is the only energy source used in office buildings in Senegal, the $CO_2$ emissions are calculated using the $CO_2$-emission factor of electricity produced in Senegal (1.10 kg $CO_2$/kWh). The indices of performance estimated for each design alternative are integrated into a database composed of 54,000 design alternatives.

## 5. MULTICRITERIA EVALUATION

Design alternatives are compared using three criteria: energy, $CO_2$ emissions, and cost. The indices to be considered for each of these criteria may take on one of the five following forms:

- the embodied factor (energy, $CO_2$, or cost) alone ($\Delta E_0$);
- the operating factor alone, at the end of first year of operation ($\Delta O_1$);
- the operating factor alone and cumulative (during the life-cycle) ($\Delta O_L$);
- the total factor (embodied + operating), at the end of first year of operation ($\Delta T_1$);
- the cumulative total factor (during the life-cycle) ($\Delta T_L$).

As an example, Table 1 shows how five design alternatives are compared in terms of $CO_2$ emissions using the five forms of the three criteria mentioned above.

Table 1 Example of evaluating design alternatives with $CO_2$ emissions as criterion.

| | $\Delta E_0$ (kg $CO_2/m^2$) | $\Delta O_1$ (kg $CO_2/m^2$) | $\Delta O_L$ (kg $CO_2/m^2$) | $\Delta T_1$ (kg $CO_2/m^2$) | $\Delta T_L$ (kg $CO_2/m^2$) |
|---|---|---|---|---|---|
| **Alternative 1** | 0.0 | 13.0 | 390.0 | 13.0 | 390.0 |
| **Alternative 2** | 0.0 | 13.1 | 393.0 | 13.1 | 393.0 |
| **Alternative 3** | -5.3 | 10.6 | 318.0 | 5.3 | 312.7 |
| **Alternative 4** | -5.3 | 15.4 | 462.0 | 10.1 | 456.7 |
| **Alternative 5** | -0.2 | 4.5 | 135.0 | 4.3 | 134.8 |

For the criterion "cost", the cumulative total factor is the life cycle cost. In this study, the present value of the energy cost savings over the life-cycle, denoted by $PC_d$, is given by (BEE-QC, 1984):

$$PC_d = PC_1 \times \left[ \frac{1-(1+t)^{-d}}{t} \right] \quad (1)$$

where:

- $PC_1$ : savings at the end of the first year of operation
- d : life-cycle (years)
- t : discount rate.

The multicriteria evaluation requires the integration and comparison between indices having different units (e.g., energy cost and $CO_2$ emissions). The approach used in this study comprises three steps: (1) scoring of each design alternatives for each criterion, (2) weighting each criterion, and (3) calculating the overall or final score of each design alternative in a manner similar to what is done in BEES (Lippiatt, 1998) for instance.

## 5.1 Individual scoring for each criterion

For each criterion, each design alternative receives a score on a 0 – 100 scale. The design alternative with the highest index ($I_{max}$) for a given criterion receives a score (called COTE) of 100 with respect to that criterion. A maximum index corresponds to maximum energy or cost savings, or to the maximum reduction of $CO_2$ emissions. The design alternative with the smallest index ($I_{min}$) for a given criterion receives a score of 0 with respect to that criterion. All other design alternatives receive scores (I) between 0 and 100, calculated based on the following formula:

$$COTE = \frac{100 \times (I - I_{min})}{I_{max} - I_{min}} \quad (2)$$

## 5.2 Weighting among criteria

The weighting expresses the preference given by the user to each criteria (energy savings, reduction of $CO_2$ emissions, and cost savings). A relative weight $w_i$ is given to each criterion i. The sum of the three weights must equal to 1. There are several approaches for assessing the weights (e.g., Kleindorfer et al., 1993). In the present case, characterised by only three criteria, the method of points allocation is considered to be the most appropriate. In this method, the user is simply asked to distribute 100 points among the criteria. The amount of points obtained by each criterion represents the percentage of its weight in the set.

### 5.3 Final score

The overall label of performance of each design alternative is assessed by evaluating the final score (COTFIN). Greater is the final score, better is the design alternative. The final score of a design alternative is the weighted sum of its scores for each criterion:

$$COTFIN = \left(w_E \times COTE_E\right) + \left(w_G \times COTE_G\right) + \left(w_C \times COTE_C\right) \qquad (3)$$

where:

- $w_i$ : weight of the criterion “i” (E for "energy" / G for "$CO_2$" / C for "cost")
- $COTE_i$ : score of the alternative for the criterion “i”.

## 6. DECISION SUPPORT SYSTEM

The decision support system (DSS) integrates the evaluation method described in the preceding section. The DSS developed using Borland Delphi® is called BURSEN (French acronym for "Office buildings in Senegal") and operates under the Windows® environment. BURSEN is endowed with a user-friendly graphical interface that combines flexibility, ease of use, and explicit handling of errors.

The software operates by project, which corresponds to an office building to design. The user can set the evaluation parameters (the cost of electricity, the economic lifespan, the discount rate for the determination of the life cycle energy cost, and the weights of each criterion) and the embodied factors which will apply to all design alternatives within a project (Figures 1 and 2).

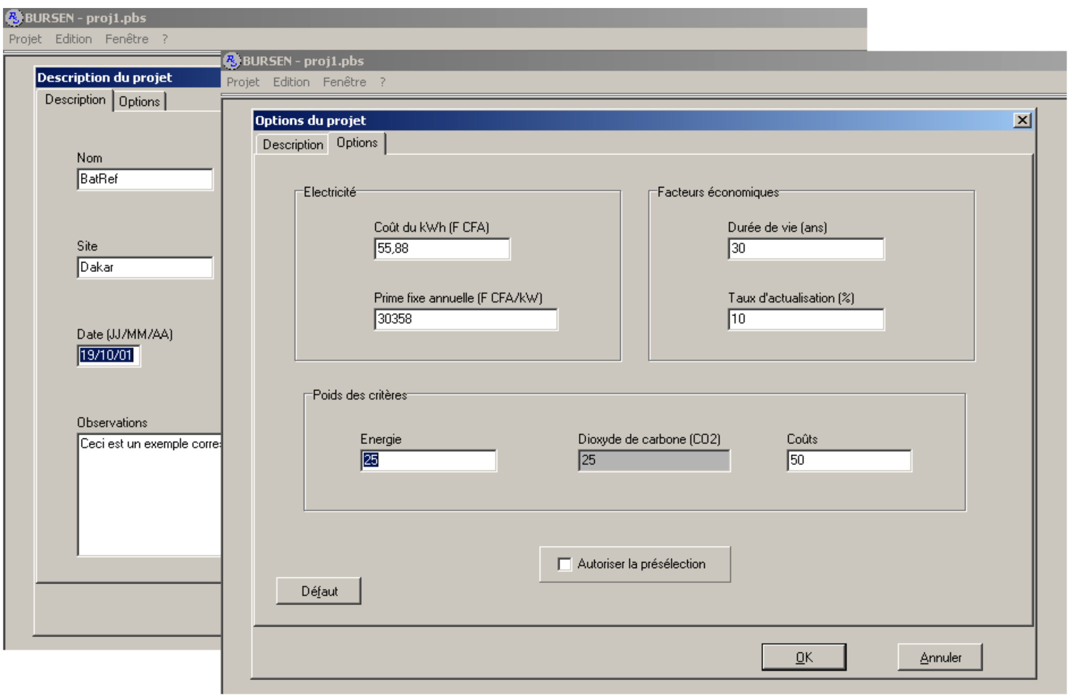
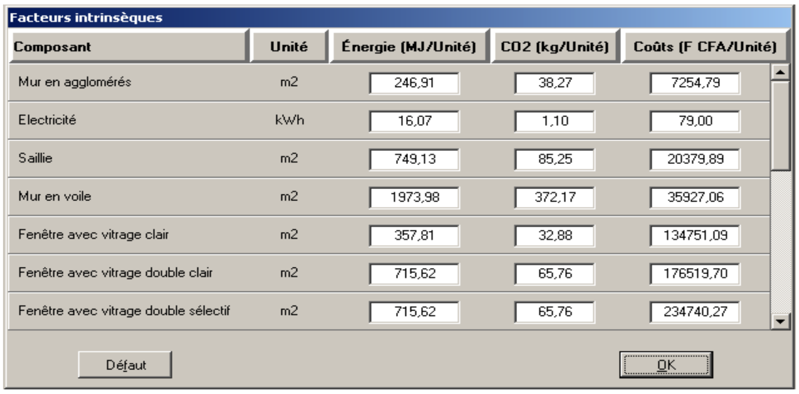



Figure 1 Windows used to set the evaluation parameters.



Facteurs intrinsèques

| Composant | Unité | Énergie (MJ/Unité) | CO2 (kg/Unité) | Coûts (F CFA/Unité) |
|---|---|---|---|---|
| Mur en agglomérés | m2 | 246,91 | 38,27 | 7254,79 |
| Electricité | kWh | 16,07 | 1,10 | 79,00 |
| Saillie | m2 | 749,13 | 85,25 | 20379,89 |
| Mur en voile | m2 | 1973,98 | 372,17 | 35927,06 |
| Fenêtre avec vitrage clair | m2 | 357,81 | 32,88 | 134751,09 |
| Fenêtre avec vitrage double clair | m2 | 715,62 | 65,76 | 176519,70 |
| Fenêtre avec vitrage double sélectif | m2 | 715,62 | 65,76 | 234740,27 |



Figure 2 Window used to set the embodied factors.

For each project, the architect defines different design alternatives which are entered using a window such as the one shown in Figure 3. In essence, by using this window, the user selects which alternative, among the 54,000 available in the data base, is considered.

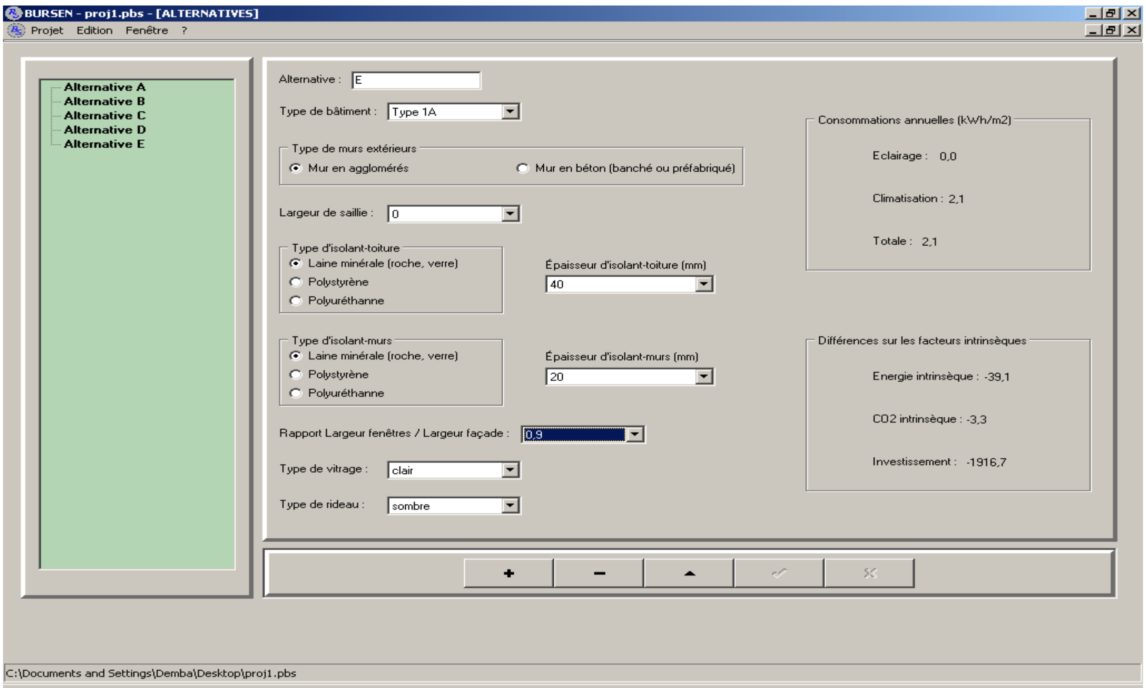



Figure 3 Window to select different design alternatives.

The results of the evaluation are presented under tabular, or graphical forms using charts such as the one shown in Figure 4. The results presented in Figure 4 correspond to the evaluation of a particular selection of five design alternatives (A, B, C, D, E) with $COTE_E = 0.25$, $COTE_G = 0.25$, and $COTE_C = 0.50$ . In this particular case, alternative D has a final score of 100 and represents the best alternative. In fact, it represents the best alternative for each criterion since it has a maximum score (25,25,50) in each category.

## 7. DISCUSSIONS

Results such as the ones presented in Figure 4 are subject to the selection of the values of $COTE_E$, $COTE_G$ , and $COTE_C$ . However the DSS is flexible and the user may easily conduct sensitivity analyses to evaluate the impact of several design alternatives.

The database might contain inherited inaccuracies due to: (1) the selection of this particular reference building as a typical office building for Dakar, (2) the estimation of embodied energy in building materials and the corresponding $CO_2$ emissions, and (3) the simulation of annual energy consumption.

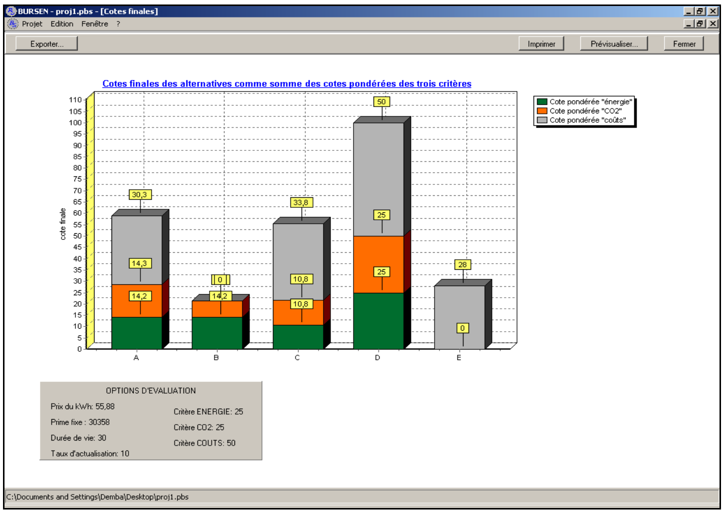



Figure 4 Report presenting the final results under graphical form.

## 8. CONCLUSION

This paper described the development of a computerised decision support system (DSS) intended to help architects in Senegal optimise the design of office buildings. The evaluation criteria are: the energy savings, the reduction of carbon dioxide emissions and the cost savings, all determined on a life cycle basis. The DSS is called BURSEN and holds a highly user-friendly interface. There are some imprecision sources in the DSS, however they are well counterbalanced by the flexibility of the tool, the possibilities of sensitivity analyses, and finally by the fact that the decisions are taken on a relative basis, and not using the absolute value of each index.


## 9. ACKNOWLEDGEMENTS

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