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Developing a new decision support tool for sizing louvers in hot and humid climates concerning light efficiency and building energy gain
Building Simulation 2023 Conference

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Abstract

Incorporating passive systems, such as louvers, into building design can significantly reduce energy consumption and carbon footprint by maximizing natural ventilation and daylighting, thereby reducing reliance on mechanical climate control systems. In this article, we present a novel decision support tool designed to optimize the sizing of louvers in hot and humid climates, considering solar protection, light efficiency, and energy gain. Using three performance coefficients (Cm, CLD, and CECC) and two performance labels, the tool enables architects and engineers to make informed decisions on louver dimensions, material selection, and orientation. Through a series of case studies, we demonstrate the tool's effectiveness in improving louver performance and energy efficiency while maintaining occupant comfort. This innovative approach offers valuable insights for sustainable building design in challenging climatic conditions.

Highlights

- Development of a decision support tool for determining optimal louvers size in hot and humid climates that considers solar protection ("Cm"), light efficiency ("CLD"), and energy gain ("CECC").
- Louvers efficiency evaluation uses three coefficients to determine their effectiveness in optimizing solar protection, daylighting, and building energy efficiency.
- Development of a simplified, user-friendly tool for design offices and architects to optimize solar protection and daylight efficiency in buildings without using simulation software.

Introduction

In recent years, reducing building energy consumption has become an increasingly important issue due to the environmental impact of building energy consumption. Buildings consume significant energy and are responsible for a considerable portion of global greenhouse gas emissions. Buildings account for nearly 40 % of the world's annual energy consumption. Due to their reliance on nonrenewable energy sources, traditional methods of reducing energy consumption, such as heating, ventilation, and air conditioning systems, have limitations. Consequently, passive solutions have emerged as a viable alternative for reducing building energy consumption (Sadineni et al., 2011). Louvers are horizontal slats or blades that can be adjusted to regulate the light and heat entering a building (Tao et al., 2020). The addition of louvers contributes to the reduction of heat gain, which subsequently improves thermal comfort. By effectively controlling solar radiation, louvers mitigate excessive heat transfer into the space, creating a more comfortable indoor environment (Sghiouri et al., 2018). The window-to-wall ratio and shading parameters impacted how much energy was used for cooling and lighting in perimeter spaces (Tzempelikos and Athienitis, 2007). Therefore, incorporating louvers into the design of a building can have a significant impact on its overall energy efficiency and sustainability. In Italy, it was found that using the right shading devices could save between 8 and 20 % of a building's total energy use each year (Bellia et al., 2013). Solar shades work best in warm summer climates because they reduce the need for cooling systems while increasing the need for heating and lighting systems because less sunlight enters the building. Therefore, it is crucial to carefully analyze the climate and location of a building before deciding on the type of shading device to be used, as it can significantly impact the overall energy efficiency and sustainability of the building. Architects and builders must consider using louvers as a viable option for reducing energy demand in residential buildings. The benefit of louvers is that they can reduce energy demand for heating and cooling in residential buildings (Pacheco et al., 2012). Various factors, such as the width and angle of the blades, the distance between the blades, and the orientation of the louvers relative to the sun's position, influence the energy-saving effectiveness of the louvers. The most significant potential for energy savings could be realized by installing louvers in cities with high summertime solar exposure (Palmero-Marrero and Oliveira, 2010).

Optimizing louvers is crucial to balance radiation impact and occupant comfort, as it helps prevent excessive energy consumption from cooling methods while ensuring a well-lit space. Parameters such as slat

width, angle, and distance can be adjusted to regulate light, heat, and shading. Parametric optimization, a process involving algorithms and computer programs, allows architects and artisans to explore and evaluate various design options based on specific criteria. However, affordable optimization options are not easily accessible to small-scale builders and designers due to the need for specialized software and technical expertise. As the demand for passive solutions grows, more accessible and cost-effective methods for optimizing louvers are expected to emerge, supporting their use as an effective passive solution to reduce building energy consumption.

This paper proposes the creation of a tool for louvers calculation during the early phases of building design. This application is designed to be user-friendly and does not require numerical simulations. This article is organized as follows: first, the implementation of numerical simulations for calculating coefficients proposed in the tool's database will be described. The design methodology for the tool will then be presented. Then, we will present the interface and use of the tool through an analysis of the results and discussions.

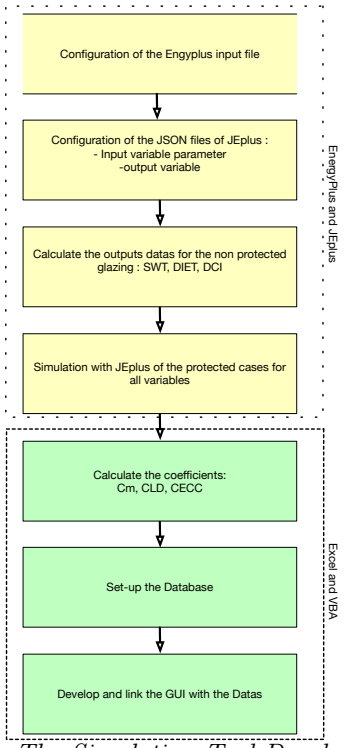

Figure 1: The Simulation Tool Development Process

Methodology

The subsequent paragraphs explain the various steps depicted in Figure 1. The JEplus implementation of the EnergyPlus model and its multi-parametric simulation are described initially. In the second step, the Energyplus output variables that were used to calculate the coefficients are presented. The coefficients used to create the database are then presented. Finally, the implementation of the coefficients database's graphical user interface is explained.

Simulation Set-up

All thermal and photometric numerical simulations were conducted utilizing the EnergyPlus software (US Department of Energy, 2019). Engineers, architects, and researchers use this program in the building industry for energy simulation calculations. Additionally, jEPlus (Zhang et al., 2016) is used for the multi-parametric simulations.

Simulation parameters

Test case

A simple rectangular-shaped building from one of the EnergyPlus test cases has been selected as the simulation's basis. The building is 600 *cm* wide and 800 *cm* long, and the height of the conditioned space is 270 *cm*. The interior has a mean coefficient of reflection of 50 %, and the height of the usable plane is 85 centimeters. These specifications and dimensions provide a controlled and standardized environment for conducting simulations, enabling the consistent evaluation of various design options and optimization strategies. Using this test case, we can accurately evaluate the impact of different design elements on building energy consumption and daylight efficiency, thereby informing the development of more sustainable and energy-efficient building practices.

Louvers configuration

The studied solar protection is an adjustable-blade sunshade, as shown in Figure 2. The thickness of the slats is 3 *cm*. The material is not considered (considered to be adiabatic) so as not to limit the user's selection to existing materials and to leave the door open for materials to be developed in the coming years.

The selected study scenarios allowed for the modulation of various geometrical parameters of solar protection, including the parameters listed in table 1.

Table 1: Parameters values used for the parametric simulations

	Parameter name	Minimal value	Maximal value	Step
Louver parameters	Slat angle	0	50	10
	Slat width	5	25	5
	Slat separation	5	45	5
	Opening orientation	45	315	45
	Shading rate of the glazing	25	100	25
Climatic parameter	Weather file location	Réunion and Mayotte		

To perform all simulations, we used the EnergyPlus "Window Material: Blind" designed to model solar shading devices. This model of EnergyPlus, which has been previously validated in the literature (Mateus et al., 2014). EnergyPlus blinds are louvered solar protection devices. In contrast to the "shade" tool, the optical properties of the blades in "blinds" are highly dependent on the angle of incidence. Addi-

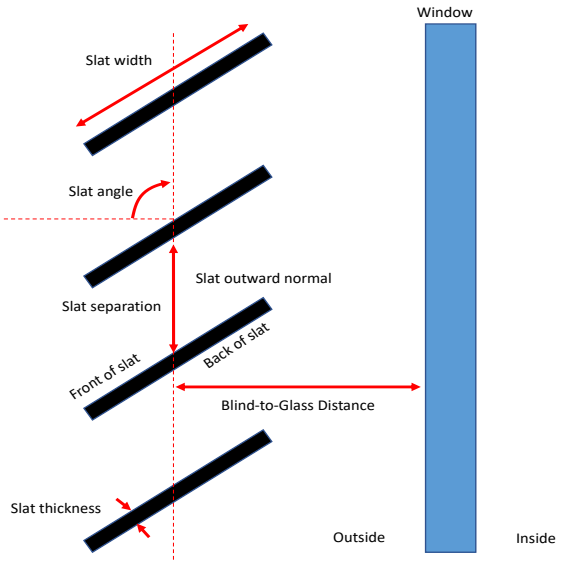

Figure 2: Louver configuration and parameters used in simulations

tionally, depending on the angle of the blades and the profile angle of the incident direct radiation, a portion of the incident direct radiation can pass between the blades, resulting in a direct component of the transmitted radiation. These components can be placed either outdoors or indoors. Therefore, this tool is highly applicable to our case study. In order to eliminate the thermal influence of the sunshade blade material, its reflectance, transmittance, and emissivity were all set to zero.

Weather conditions

The simulations were conducted for Reunion and Mayotte's climates. Gillot weather file was used for Reunion, which has a year-round tropical climate with high temperatures and humidity. In February, the average temperature is around 27 °C, with highs exceeding 30 °C. Dzaoudzi weather file was used for Mayotte, which has a tropical savanna climate with high temperatures and humidity. In May, the average temperature is around 27 °C, with highs exceeding 30 °C. The design strategy focused on solar protection to reduce the heat entering the building, accounting for both direct and diffuse solar radiation. EPW climate files were used for energy simulations to generate the foundational data for the tool.

The simulations spanned a year, with data processing occurring during two distinct periods. The louver-type solar protection serves two distinct purposes: shielding interior spaces from external radiation while allowing natural light to enter (in February, the hottest month) and shielding occupants from low-angled rays in June to maintain visual comfort. Depending on the preferences of the tool's user, February is selected for thermal comfort and June for visual comfort.

Data base of coefficient setting-up

Coefficients are calculated using data extracted from the EnergyPlus calculation results to evaluate solar shading performance. Simulations are executed with the parameters specified in Table 1. The coefficients listed below are defined as follows.

Cm coefficient

According to Figure 3, the coefficient Cm is defined as follows:

$$Cm = \frac{SWT_{P_{MTH,MAX}}}{SWT_{NP}} \tag{1}$$

In equation 1 SWT_{MTH} denotes the "Surface Window Transmitted Solar Radiation Rate" output of EnergyPlus used to calculate the solar radiation coefficient. This output, in $[W]$, represents the total amount of solar radiation transmitted to the room's interior by the glazing. At an hourly time step, simulations are run without solar protection $SWT_{(NP(MTH,MAX)}$ and with solar protection $SWT_{(P(MTH,MAX)}$. The returned values correspond to the highest possible monthly values ("MTH, MAX"). According to the regulations, this coefficient's "validity" range has been set between 0.15 and 0.70. Below this threshold, we deem the glazing to be inadequately protected. Over that, the level of solar protection is excessive. The Cm factor considers direct and diffuse solar radiation transmitted by the glazing. It corresponds to the exposure factor of the glazing, or more precisely, the solar protection efficiency.

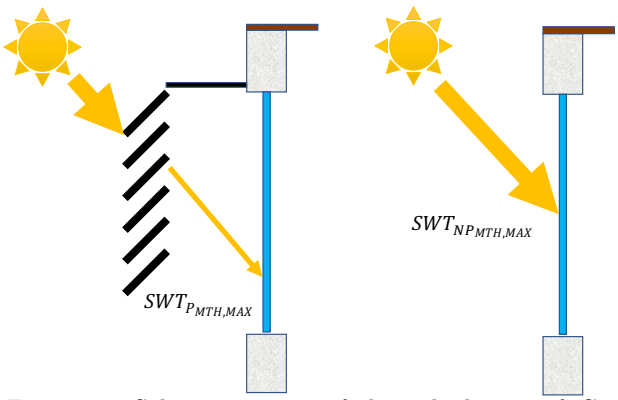

Figure 3: Schematic view of the calculation of Cm coefficient

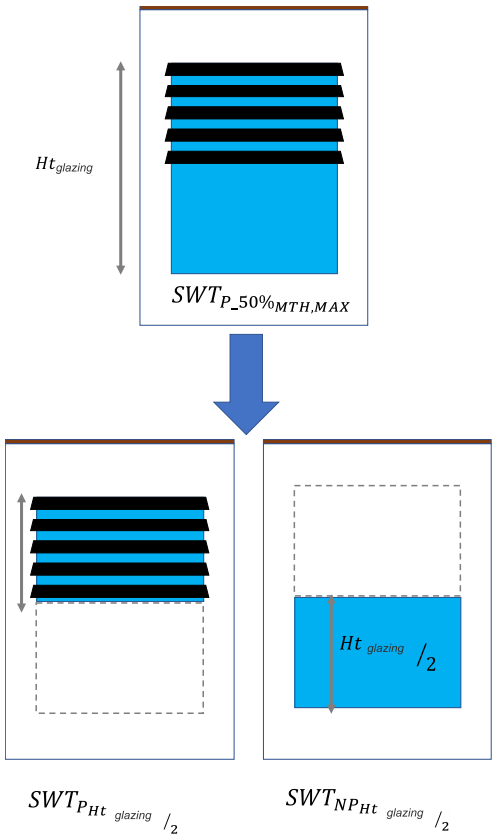

Figure 4: Methodology to calculate the Cm coefficient with 50 % of glazing shading

Cm coefficient for partial glazing shading

As mentioned in table 1, the possible configurations include variations in the solar shading coverage area. Four distinct shading levels are proposed, ranging from 100 % (shading over the entire glazing surface) to 25 % (shading over 25 % of the glazing height, beginning at the top) in 25 % increments. Figure 4 depicts these four arrangements.

Because the relations are not linear, applying a coefficient corresponding to the shading rate to the 100 % configuration results is impossible. Given the number of simulations and the fact that the numerical tool does not permit direct integration of these configurations, we propose a numerical method for simulating the various rates. We have assumed that the energy transmitted during partial shading is proportional to the height of the glazing. This method relies on the following premise: We simulate two vertically stacked glazings whose total height matches the height specified in the test case (200 cm). One is completely shaded by solar shading, whereas the other is not. The height of the two glazings will then vary to match the studied shading while maintaining a total height of 200 cm. For example, in the case of 50 % shading (Figure 4), the test case glazing is divided into two 100 cm-high panes, one of which is fully shaded and the other of which is not. The protected pane measures 50 cm, while the unprotected pane measures 150 cm.

In the scenario depicted in Figure 4, the solar radiation coefficient Cm combines the radiation transmitted by protected and unprotected portions. For a 50 % shading example, then, the equation 1 becomes:

$$Cm = \frac{SWT_{Pht_{glazing/2}} + SWT_{NPht_{glazing/2}}}{SWT_{NP}} \quad (2)$$

CLD coefficient

The CLD coefficient is computed similarly to the Daylight Autonomy factor.. CLD is calculated as follows:

$$CLD = \frac{DIET_{(NP,MTH)}}{(DIET_{(P,MTH)}}. \quad (3)$$

On the useful plane, the CLD considers the direct and diffuse illuminance arriving at the two reference points inside the room. It corresponds to the solar shading impact rates on daylight autonomy. $DIET_{MTH}$ is the "Daylighting Reference Point Daylight Illuminance Setpoint Exceeded Time" output of EnergyPlus. This output is the number of hours where daylighting is more significant than 300 lux according to European standards EN 12464-1.

CECC coefficient

The coefficient of energy consumption (CECC) for HVAC is:

$$CECC = \frac{DCI_{NP,YEAR}}{DCI_{P,YEAR}} \quad (4)$$

The CECC corresponds to the energy savings rate for a year generated by solar protection in a room with theoretically active air conditioning when the indoor temperature exceeds 25 °C. The "District Cooling Intensity" output of EnergyPlus is $DCI_{P,YEAR}$. This output returns the cumulative annual electrical consumption per room area a hypothetical air conditioning device requires to maintain a specified indoor temperature at 25 °C. Simulations are conducted without solar protection $DCI_{NP,YEAR}$ and with solar protection $DCI_{P,YEAR}$. The returned values represent the cumulative annual totals.

Non protected glazing calculation

All coefficients in the denominator include outputs without solar protection. Transmitted energy ranges from 838 W in June to 284 W in February on Reunion Island, decreasing towards the south. For each simulation, the highest monthly daily average is used.

Thermal comfort prioritizes February's Cm value, while visual comfort focuses on June. The CLD coefficient represents cumulative monthly values for the chosen criteria and is dynamically displayed as users input room protection information. The coefficient values for each simulation are compiled in a spreadsheet from which the graphical user interface retrieves the data. This process allows users to quickly visualize and analyze the results of each configuration, enabling them to make informed decisions based on the data.

Tool graphical user interface

Figure 5: Louver label level of Solar protection performance

The created tool is depicted in Figure 6. It has been implemented in the VBA environment. The tool's window is divided into four sections. The left side of the screen prompts the user to select one of the two previously defined and presented locations. The user can therefore select a particular orientation. The user will then have the option to choose between natural ventilation and air conditioning. He can also specify whether thermal or visual comfort is his top priority. The instrument's central portion is divided into two sections. The first pertains to the definition of the louvers parameters (Table 1), and the second to the presentation of the results for the three coefficients and the louvers level label. The right side of the display allows the user to view the configuration's results. There are two possible perspectives, a cross-section, and a front view. It provides an overview of the completed design. A second window of the tool displays the results as an abacus. A second window of the tool provides access to a 3-table, color-coded result chart ranging from green to red.

Louver Level Label

In this work, criteria for evaluating the performance of sunshades in terms of the coefficients Cm, CLD, and CECC have been established. We have created a sunshade performance label to make it easier for the user to comprehend the louvers' performance. Table 2 defines the performance labels for the louvers. To associate a color with each performance level, the values of CLD and Cm coefficients were arbitrarily divided into seven ranges, evenly distributed to ensure equitable representation. This table contains information regarding the value ranges for the performance attribute.

Table 2: Definition of the Level Label Perfomance

	Daylight Performance	Solar Protection
Range	Label Level	
$x > 0,85$	Bad	Good
$0,71 < x < 0,85$	Fairly Bad	Fairly good
$0,57 < x < 0,71$	Moderately bad	Moderately good
$0,43 < x < 0,57$	Moderate	Moderate
$0,29 < x < 0,43$	Moderately good	Moderately bad
$0,14 < x < 0,29$	Fairly good	Fairly Bad
$< 0,14$	Good	Bad

This allowed us to establish a seven-color scale for qualitatively evaluating the protection against solar radiation and its ability to limit artificial lighting.

Results and discussions

Glazing shading percentage influence

This section presents the results for a north-facing protected window orientation. This orientation is selected because it corresponds to the cardinal direction in which the sun's path is most influenced.

Table 3: Influence of glazing percentage protection

Glazing protection percentage				
Réunion				
	100	75	50	25
Cm	0.28	0.45	0.63	0.81
CLD	0	0	0.56	$O.89$
CECC	0.54	0.51	0.36	0.19
Daylight Level	Bad	Bad	Moderate	Good
Solar protection Level	Fairly good	Moderate	Moderately bad	Fairly bad
Mayotte				
Cm	0.28	0.46	0.64	0.82
CLD	0	0	0.59	0.9
CECC	0.54	0.43	0.33	0.15
Daylight Level	Bad	Bad	Moderately good	Good
Solar protection Level	Fairly good	Moderate	Moderately bad	Fairly bad

The results of the percentage of glazing protection on the louvers' performance of the louvers are presented in Table 3 At 100 % of shading glazing, the tool rates the level of solar protection as excellent. This material has a Cm coefficient of 0.28 and a 50 % air conditioning gain. Unsurprisingly, the tool rates the illumination level as very poor because the blade density over the glazing height needs to be lowered to permit adequate daylight for the same width and width parameters (5 cm and 5 cm). Regardless of the slat angle, finding the optimal performance of all three parameters is impossible. This configuration is attractive in terms of solar shading but not in terms of the building's natural ventilation. The solar protection's blade density would not be suitable for natural ventilation. Smaller width values necessitate more comprehensive blade width values when the glazing

is completely obscured. The same pattern holds for Mayotte, with a Cm coefficient of 0.28 and a cooling gain of 56 %. By reducing the glazing shading to 75 % for the minimum configurations of width, spacing, and orientation of the louvers, we obtain comparable values for Reunion and Mayotte. The Cm value is 0.46, with a performance label classifying the protection as average, a CLD of 0, and air conditioning savings of 51 % and 43 % for Mayotte and Reunion, respectively. At 50 % solar protection, solar shading permits more natural light to pass through. The CLD raises to 0.59, which makes the shading device's quality moderately good. However, it contributes to a decrease in solar shading performance by increasing the CLD to 0.64. Reunion gains 36 % in air conditioning energy consumption, while Mayotte gains 33 %.

The solar protection is no longer optimal for a minimum glazing shading rate of 25 %. Reunion Island has Cm and CLD coefficients of 0.81 and 0.89, respectively. Mayotte demonstrates similar outcomes. The air conditioning's energy consumption increases linearly until it reaches 19 %. In this configuration, solar protection performance is inferior. It is, therefore, a configuration that only permits the three criteria to be optimized. Maintaining the minimum values of the characteristic parameters of solar protection makes it easier to locate solar protections that meet the required levels. 50 % shading yields the most favorable results in configurations with a high density of shading devices. Other parameters can be adjusted to improve the outcomes. Following is a presentation of the effect of louver spacing.

Slat separation distance influence

Table 4: Influence of Slat Separation Parameter

	Slat separation in cm		
	10	30	40
	Réunion		
Cm	0.24	0.62	0.69
CLD	0	0.19	0.34
CECC	0.57	0.33	0.26
Daylight Level	Bad	Fairly bad	Moderately bad
Solar Protection Level	Fairly good	Moderately bad	Moderately bad
	Mayotte		
Cm	0.23	0.63	0.71
CLD	0	0.12	0.35
CECC	0.58	0.33	0.26
Daylight Level	Bad	Moderately good	Moderately bad
Solar Protection Level	Fairly good	Moderately bad	Fairly bad

Slat orientation influence

The results of the percentage of glazing protection on the louvers' performance of the louvers are presented in Table 4. This section examines the impact of the distance between the solar protection louvers. To study this parameter, we set the shading percentage of the glazing to 100 %. The parameters for the width and angle of the slats will be set to 10 *cm* and 30°, respectively. In the case of Reunion Island, the solar protection is rated as quite efficient for a distance between the louver blades of 10 *cm*. The performance against natural lightning is rated as inadequate. Mayotte demonstrates similar outcomes. For both locations, the increase in air conditioning consumption is approximately 57 %. These results indicate that a minimum distance of 30 *cm* must exist between the louvers for daylight autonomy to be significantly affected. With a Cm coefficient more significant than 60 %, the solar protection performance for 30 and 40 *cm* spacing decreases considerably. Keeping the minimum values for the angle and width of the blades makes it challenging to find the optimal solution for our three objectives. By concentrating solely on the distance between the blades, the air-conditioning savings are on the order of 30 %, and the lighting autonomy is 12 %. When we attempt to make the distance between blades proportional to their width. It can be seen that when spacing equals width, the CLD is unaffected. Alternatively, when the spacing value is equal to twice the width of the blade, there is a constant 8 % increase in daylighting autonomy, a 50 % improvement in solar protection, and a 40 % reduction in air conditioning energy consumption.

Table 5: Separation/Width Ratio influence on louvers performance

	Cm	CLD	CECC
	Width =10cm		
Separation/Width Ratio			
1	0.31	0	0.54
2	0.53	0.8	0.4
3	0.64	0.29	0.3
	Width =15cm		
2	0.55	0.1	0.39
3	0.63	0.26	0.32

For a spacing ratio equal to three times the length of the blade, the daylight autonomy decreases (Cm=0.64) at the expense of the protection performance. The increased energy consumption is due to the large spacing that allows a great deal of sunlight to pass through and contributes to the rise in room temperature. Taking a length-to-spacing ratio of 2 is a good compromise.

Slat angle influence

In this section, we investigate the effect of blade angle on solar protection performance. When the spacing between the slats is equal to the width of the slat, increasing the slat tilt tends to increase solar protection by decreasing the Cm. Overall, the solar shading is rated as fair to good. However, increasing the angle

has no impact on daylighting. The CLD coefficient is zero for all tilt values. Solar protection improves with increasing slat angle for a maximum slat spacing of 40 *cm*. The values of the Cm coefficient vary between 0.5 and 0.38. For this maximum spacing, the gain in daylight remains low with 6 % for an angle of 10° and 1 % for 20°, and it is canceled out for higher values. The CECC coefficient is between 0.44 and 0.52. Although these energy-saving results are very interesting, they are achieved at the expense of efficient daylighting.

Conclusion

This study has successfully developed a novel decision support tool for sizing louvers in hot and humid climates, considering crucial aspects such as solar protection, Daylight efficiency, and energy gain. The methodology employed in constructing the tool has led to using three performance coefficients, namely Cm, CLD, and CECC, which facilitate a comprehensive assessment of various louver configurations. The thorough analysis of different configurations has showcased the tool's capability to enhance the performance of louvers, ensuring improved energy efficiency and occupant comfort. The presented decision support tool has the potential to significantly contribute to the design and implementation of sustainable and efficient building envelope solutions in hot and humid climates. From a future perspective, integrating a multi-objective optimization algorithm into the tool will further enhance its ability to provide optimal solutions for users. This advancement will allow for the simultaneous optimization of multiple performance criteria, leading to more efficient, comfortable, and sustainable building designs. Overall, this study demonstrates the considerable value of decision-support tools in addressing the challenges of building design in extreme climate conditions and contributes to the ongoing efforts to promote sustainable and low-carbon built environments.

Acknowledgment

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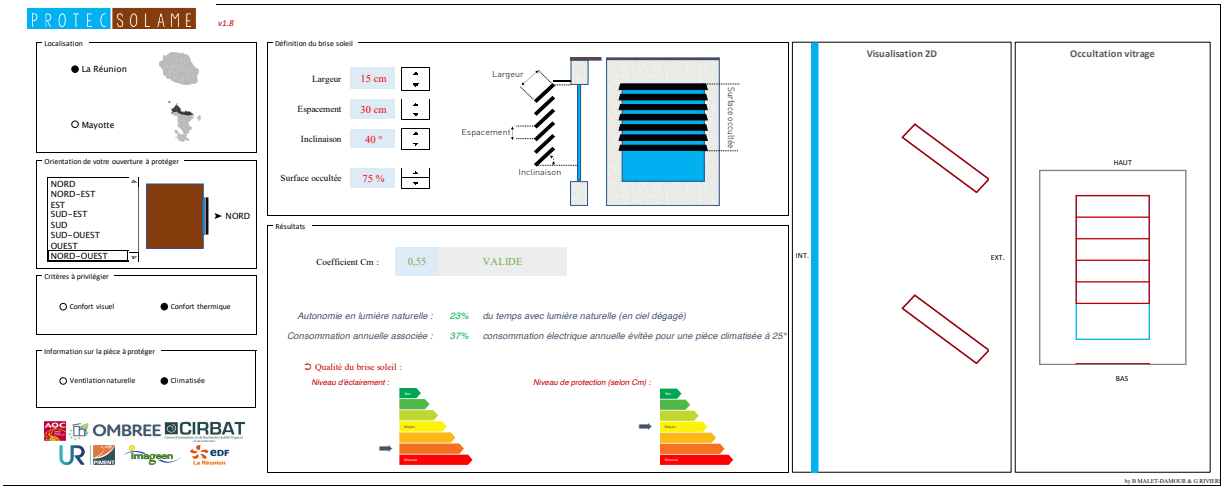

Figure 6: GUI of the tool