DAYLIGHTING AND THERMAL STRATEGIES IN THE DESIGN PROCESS:
CASE STUDY OF LAVAL UNIVERSITY’S NEW MEDICAL FACULTY BUILDING

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ABSTRACT

This project proposes an illustration of an integrated approach to the study of the luminous and thermal environments in the design process for the new extension of an educational building at Laval University, in Canada. Simulation laboratories were used in the analysis for the prediction of physical ambiences of the future environment as well as digital tools of analysis. Moreover, simulation tools were especially developed for the analysis of the physical phenomena to reinforce the architectural applications of passive solar design strategies. The balance between thermal and lighting optimization is critical to the success of the project where bioclimatic strategies are targeted. The research team has developed a methodology that allows the comparative evaluation of such compromise in the design process. The validation of design proposals was therefore carefully integrated to the architectural developments of the project.

Keywords: atrium, daylight, energy, environmental controls, simulation, thermal comfort, wind studies, bioclimatic architecture, integrated design process.

1. INTRODUCTION

The project consists in the new extension of the Vandry University building in Quebec City, Canada, into a larger Faculty that supports the interdisciplinarity of medecine. The heart of the project consists of two atria, one of which should integrate plants, as well as an external courtyard that facilitates exchanges between invited students, professors/researchers and professionals. Figure 1 shows the southwest perspective of the extension, whereas atria skylights (top left of the image) and other passive solar design strategies such as sunshading devices for the library and horizontal reflectors for the offices are illustrated. A new courtyard is integrated, as well as a basin for the retention of rainwater located under the extruded box of the library of the same facade.

Fig. 1: Left: Perspective of the main entry of the new extension of the Vandry Pavilion.

Researchers from the GRAP (Group of Research on Physical Ambiences) were actively involved in the simulation studies and analysis of design proposals using a diversity of tools throughout the design process. This research demonstrates the interest to integrate the appropriate tools of analysis within the discussions with architects and engineers and to use them conjunctively, enabling a more global validation of the results at the three
scales of design: the urban scale (site analysis), the architectural scale and the scale of the detail.

2. THREE SPACES: A CASE STUDY INTEGRATING LIGHTING AND THERMAL ANALYSIS

Although the overall building was considered in the process of design and analysis, this paper mainly deals with the design of three typical spaces: two atria (section 2.1), the new courtyard (section 2.2) and its surrounding offices on the southwest façade (section 2.3).

2.1 The design of atria

The approach for the study of the luminous environments is experimental and parametric in which various configurations, initially identified with LUMcalcul [Demers et al., 2004] (fig. 2), a worksheet based on the daylighting formula of Tregenza and Loe [1999], are modified to reach results considered optimal. The artificial sky of the School of Architecture (fig. 4) is used to simulate an overcast covered sky.

A thermal study accompanies the lighting studies of the atria in which the percentage of glazed roof was simulated to optimize the daylighting availability. The research thus addresses questions that will determine the best compromise between a good daylight of the atria, a reduction of the heating load as well as a minimization of the cooling load. The solar angles perpendicular to the surface of the skylights of the building in December, March/September and June were examined to determine the more efficient inclination of the glass. Figure 3 illustrates a typical graph representing the conditions at the equinoxes. It was also important to ensure that the three simulated glass inclinations were efficient to clear out most of the snow accumulated on the skylights during the cold season. The research demonstrates that in winter, it is necessary to support the smallest angle of incidence to maximize passive solar heating whereas in summer and in-between seasons, it is necessary to maximize the angle of incidence to minimize the direct solar gains. The 65 degree inclination responded more efficiently to the thermal requirements and was thus provided as a design variable to pursue the daylighting simulations and optimize the design of the visual ambience.

Fig. 3: Graph of the incidence of sunlighting perpendicular to the glass of the skylights in relation to the time of day, at the equinoxes (March 21st and September 21st).

Fig. 2: Typical LUMcalcul spreadsheet for the preliminary daylighting evaluation.

Fig. 4: Model of an atrium section of the building in the artificial sky at Laval University.
The experimental parametric study of the luminous environment involved various identified configurations to be simulated. They were evaluated to attain results that were considered to be optimal for the client. The artificial sky at the School of Architecture was used to simulate an overcast sky using the CIE (Commission Internationale de l’Éclairage) distribution of luminances. Figure 4 shows the physical model that was built to carry out the experiments. The overcast sky indeed presents critical conditions of daylighting in Canada, occurring in 63% of the year in Quebec City [Demers, 2001]. The average horizontal illumination produced by this artificial sky is approximately 6900 lux. The illumination data were translated into daylight factors (DF) and expressed as percentages.

A physical model was built of a whole typical section of the atria at the 1:50 scale, appropriate for the ease of observation of the various reflectors and skylights that needed to be studied. LUMcalcul [Demers et. al., 2004] was used, this time to evaluate the various reduction coefficients not considered in the physical modeling, such as the factors related to maintenance and human occupation. Several morphological configurations of the skylights were studied as well as different variables relating to the types of structures, glass, and reflectance of material surfaces. Figure 5 shows a typical data sheet that was used to gather the main results for the study of each variation of the three morphologies of the simulations. The comparative results for the study of the three main typologies are presented in the graph of figure 6. Reduction coefficients described in details in the research report were therefore applied to the resulting data of figure 6. The top images at the right of figure 5 are processed using the digital method of analysis [Demers, 1997] that allows a qualitative analysis of the lighting patterns appearing on the walls of the atria. The image analysis suggests potential sources of glare appearing in the top right of the atrium of the wall (second row of photos) for surrounding office spaces of the atrium.

Fig. 6: Graph of Daylight Factor in relation to several propositions of skylights in the atrium.

The simulations carried out with ECOtect initially consisted of variables that were identical to the readings obtained from the artificial sky experiments to validate the results provided by the software. They were used to carry out complementary transformations by holding account of a relatively precise margin of error. The digital method of analysis developed by Demers [1997] and Schlier [2000] was also used to assess potential risks of glare in the atria.

Thermal studies were mainly carried by using the PET software [Potvin et.al., 2004], a sophisticated spreadsheet that calculates profiles of thermal equilibrium in interior spaces, as well as ECOtect as a complement. The latter, originally more limited in cold climates such as Canada, was therefore left aside at some point of the thermal analysis, as very low winter temperatures could not be simulated. Wind analysis were carried out using the water...
The balance between thermal and lighting optimization is critical to the success of a project where bioclimatic strategies are targeted. The research team has therefore developed a methodology that allows the comparative evaluation of such compromise in the design process. Figure 7 and 8 show the combined thermal and lighting evaluation of several design typologies that were discussed at some point of the project. These figures show the results for the seven most relevant experiments that were performed, from experiment 1 (left of graph or table) to 7 (right). The appreciation of the results was carried out according to a scale of notation based on the results of diverse simulations. It shows that the most interesting configurations correspond to the B45 type, the skylight with three teeth of saw. Although the completely glazed configuration (B45-93/93/10, experiment 2) offers the most promising lighting for the peripheral offices and the introduction of plants, it comprises too much on the level of thermal control. The sawtooth typology appeared most interesting, as much of the daylight target was reached, offering a solution where thermal gains and losses could easily be controlled in the atrium. The typology has been further refined with parametrical studies that occurred at subsequent design stages combining the use of the various tools of analysis earlier mentioned.

2.2 The design of the courtyard

The design of the courtyard aims at creating a comfortable outdoor space for the students and researchers of the campus, as well as providing sufficient daylighting for all spaces of the new extension. The addition of a courtyard...
affects the daylighting levels of the existing building. In this regard, it was essential to ensure that the existing spaces were sufficiently daylit. The deep facade plan was therefore converted into a typology that favours the occupation of the periphery to optimise the access to light (fig. 10). Initial rules of the thumb, such as optimisation of the sky-view from all occupied spaces, were therefore used to design the initial configuration in terms of daylighting availability. ECotect simulation was also performed to validate the daylight availability of courtyard and surrounding offices (fig. 12).

The occupation of an exterior courtyard in a cold climate certainly addresses many challenges in terms of physiological comfort. In fact, extensive simulations had to be carried to prove that the space would be pleasant, especially during its potential occupation during full terms at the equinoxes. Wind studies were performed with CFD software (fig. 13) to simulate the effect of natural ventilation in the courtyard and monitor wind speeds at the critical times of the year (shown in the ECotect representation of fig. 11). Wind simulations were also carried for winter conditions to validate the patterns of snow accumulations. The slow melting of snow in sunshaded areas during the late spring season is also an indicator of thermal discomfort that could be experienced on the potential users of the courtyard.

2.3 The design of offices on the southwest facade

The southwest facade of the building is particularly exposed to solar radiation during the period of air-conditioning, which was defined of March 21 to September 21. A study has determined the optimal solar configuration to control the solar gains. The normal angles of solar incidence to the glazing were initially calculated in order to know the most critical periods to occult. Digital simulations using the
ECOtect software then enabled the determination of the optimal solar geometry. A study of the critical angles of solar radiation from December to June was therefore performed, identifying the zones that needed to be avoided for solar gains. It was then defined that the smaller normal angles of solar incidence on the glazing particularly needed to be occulted. The current practice suggests the importance to consider only the normal angles lower than 60°, the radiation being thought to be reflected at 80% of its value for higher angles. It was thus recommend that:

-At the winter solstice (December 21), the sun must be occulted from 13h00 to 15h00 to avoid glare, the solar gains being positive and decreasing the load of heating;

-At the equinoxes (March 21 and September 21), the sun must be occulted between 13h00 and 17h00 to avoid the solar gains;

-At the summer solstice (June 21), the sun must be occulted between 14h00 and 18h00 to avoid the solar gains.

Other results from this study clearly illustrated the advantage of the vertical sunshade to counter the solar gains in the cooling period between the equinoxes on a southwest façade. The vertical sunshades will be also more effective to control glare during the heating period.

Sunshading devices directly affect daylighting patterns inside a space. Daylighting considerations were immediately integrated to the solar design strategies to respond more specifically to the potential thermal gains. There are also considerations about the quality of light and view offered through a solar protection that need to be addressed early in the decision making process. Figure 14 illustrates an array of vertical sunshading devices that was proposed to provide the necessary protection of the window glass against the critical thermal gains. Such a shading protection can dramatically lower access to daylighting, a condition that become especially critical in winter whereas the overcast sky condition predominates and people are subjected to the Seasonal Affective Disorder (SAD), a temporary depression that occur more severely in January and February. The proposed horizontal sunshading device added on top of the vertical shading system provides a complementary approach that favors a more complete shading of the sunlighting pattern in the lower larger portion of the window that also acts as an exterior lightshelf. The top portion of the glass of the office is therefore not protected to allow the lightshelf to optimize the reflection of daylighting on the ceiling of the interior office space and provide a more effective distribution of light on the horizontal working plane. Figure 15 illustrates an example of the daylighting studies that were performed using ECOtect to verify several sunshading strategies on the southwest façade and their implications on the quantitative aspects of daylighting of a CIE overcast sky. The typical office on the southwest façade is represented on the left part of the image whereas the northeast office that has no need of shading device is on the right. The results aim to show that the compromise between the thermal gains and daylighting optimization should provide the best design strategy in this integrated process.

![Daylight Analysis](Image)

Fig. 14: Proposition of a sunshading strategy showing the sunlighting patterns in offices on the southwest façade.

![Daylight Analysis](Image)

Fig. 15: Daylight factor (DF) distribution of horizontal illuminance distributions in southwest and northeast offices.

The corridor between the rows of offices was also monitored with several design strategies using borrowed daylighting to ensure its viability even in the case of an electricity breakdown. It was calculated the 300mm high horizontal windows located near the ceiling would be sufficient to provide a 2% daylight factor in the corridor.
The window for borrowed light could be located on either sides of the corridor in the case of a sunshading strategy using a horizontal lightshelf on the southwest facade.

3. CONCLUSIONS

Daylighting and thermal considerations are known to be antagonistic and should therefore be integrated simultaneously, early in the design process. The case study presented in this paper identifies several issues that were tackled on daylighting and thermal aspect throughout the design of the building. Simulations occurred at the various stages of the design, using basic rules of the thumb that were later tested with progressively more advanced simulation tools such as the artificial sky. This kind of integration involves frequent and extensive communication between researchers. Communication of the applied research results between researchers (thermal and lighting) occurred almost every day whereas communication with the architects and engineers initially occurred at least on a weekly basis.

The integration of daylighting and thermal strategies are essential to attain a certain quality of life of the researchers in their new building. Moreover, it optimizes the energy performance of the building. Preliminary EE4 (software offered by Natural Resources Canada) energy simulation of the building shows that the proposed electromechanical concepts can generate a sensible energy economy. This preliminary analysis reveals that the power consumption of the building is 27% lower to the Model National Energy Code for Buildings 1997, the national energy as the buildings reference benchmark (fig. 16).

<table>
<thead>
<tr>
<th></th>
<th>Electrical Energy</th>
<th>Fossil Energy</th>
<th>Total Energy Use</th>
<th>Economy (%)</th>
</tr>
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<tr>
<td>Reference building</td>
<td>17 554</td>
<td>8 645</td>
<td>26 200</td>
<td>-</td>
</tr>
<tr>
<td>CIFSS</td>
<td>12 988</td>
<td>6 178</td>
<td>19 166</td>
<td>27</td>
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<tr>
<td>CIFSS with natural ventilation (offices)</td>
<td>12 095</td>
<td>6 350</td>
<td>18 445</td>
<td>30</td>
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Fig. 16: Energy use study using the Canadian national benchmark as a reference building.

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4. REFERENCES

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