ASSESSMENT OF MOVABLE INSULATION PANELS' ENERGY AND LIGHTING POTENTIAL FOR ADAPTIVE FAÇADES IN ARCHITECTURE

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ABSTRACT

This research focuses on the performance of movable insulation panels as manual shading devices and as an energy conservation strategy for an office space. Simulation results demonstrate the device's potential in reducing energy consumption as well as diversifying visual environment. Three main forms of panels were simulated using IES VE and Radiance module. Optimal manipulations were determined from an energy and lighting standpoint by assessing two metrics and were compared to illustrate their effects on lighting environment and energy loads. Optimal scenarios were constructed on an hourly basis to illustrate differences in energy and lighting needs. While some manipulation scenarios clearly demonstrate non compatible effects on energy and lighting performance, some scenarios can significantly improve both energy and lighting performance and should be considered. Conclusions address the potential of movable insulation panels as an effective adaptive strategy for responding to occupants needs and to changing climatic conditions.

Keywords: movable insulation, shading, energy consumption, lighting ambiance

1. INTRODUCTION

On the one side, transparency of the envelope, windows, is considered as of the 21st century essential from a sustainable architecture standpoint, for its energy benefits as well as for its biophilia features. On the other side, in Nordic climates, it is responsible for great thermal losses when not exposed to solar radiation. This incompatibility is an important challenge for designers working toward an environmental approach for architecture.

Movable insulation panels (MIP) can address this challenge. Movable insulation or night insulation comprises covering windows when they do not insure solar gains, mainly by night time, by heavy cloud covers or depending on solar orientation, and when exterior views are not needed. MIPs can be more than solely an energy conservation strategy. Their capacity to shade and reflect light (1) participates in creating a more comfortable visual environment. Such dynamic shading devices can actively respond to ever changing climatic conditions, on a daily and seasonal basis. Furthermore, MIP's manual control promotes adaptive behaviours which are considered essential in regard of environmental comfort.

1.1. Research objectives

This research analyses three types of MIPs and compares their impacts on energy consumption and on illuminance level control. It proposes assessing and classifying different daily manipulation scenarios based upon the panels' positions and on the ratio between energy saving and lighting control potentials.

It serves as an exploration of adaptive façades, in regard of movable elements and their effects on ambiances. The outcomes do not lean toward optimization of energy and lighting performances of the devices. They show the potential of movable devices and the compatibility between energy and lighting goals.

2. METHODOLOGY

The methodology used for this research is mainly parametric. Computer simulations were conducted as opposed to *in situ* studies. Although the latter will generate more valid results, computer simulations offer a greater control of an important amount of parameters and will facilitate the comparison of the outcomes. Such simulations are largely used for this type of research owing to a low-cost and to their capacity to integrate complex thermal and lighting interactions (2).

2.1. Simulation software

The well-known integrated software suite *IES VE* is used in this research. It offers a dynamic analysis of both thermal environment, through the use of *Apache* engine, and lighting environment, through the use of third party engine *Radiance*. Both engines are well validated (3,4). Reliability and 3D interface were important features in the choice of this particular software package. The use of such a suite avoids the need to remodel within different softwares as well as incompatibility problems between softwares (5).

The software's characteristics and simulations parameters are fully described in a complete dissertation of this research (6).

2.2. Simulation model

The space that is studied is an enclosed office measuring 3 meters wide by 7 meters long and by 2,85 meters high, with a south oriented window, in Quebec City[1]. The choice for an enclosed office was made to reduce the amount of variables as this research is meant as exploratory. Open spaces would add complex variables such as different use profiles for each panel of all windows of the space. Analysis of an enclosed room offers an independent assessment of the impact of one panel for one opening.

The window of the model covers nearly the entire surface of the exterior wall with dimensions of 3 meters wide by 2,75 meters high. A transparency/façade ratio of 100% is said to be the case. Since there is only one exterior wall, all other surfaces are adiabatic.

The reference model is identical as the model described above except for the fact that it is not equipped with MIPs, but also for the fact that it is characterized by a transparency ratio of 70%. Since it is given as a hypothesis that movable insulation reduces thermal losses, it is interesting to analyse the impact of MIPs on greater transparency. A transparency ratio of around 70% is common for contemporary office buildings. Fig. 1 shows the two models used for simulations.

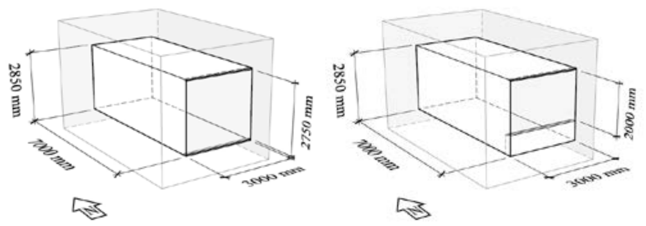

Fig. 1: (left) Simulation model with use of MIPs and (right) reference model.

Other parameters regarding the modeling and simulations inputs can be found in the dissertation (6).

2.3. Types of panels

Three main forms and movements of panels were chosen for analysis.

(1) A sliding panel (fig. 2a) represents a basic system. Sliding MIPs are currently available for Quebec City's region. They are developed and installed by Josuma inc.

(2) A vertical folding panel (fig. 2b) folds in a vertical axis. This type of MIP is being developed at this time by Josuma inc. This panel is studied here for its properties regarding shading and light reflection.

(3) A horizontal folding panel (fig. 2c) folds in a horizontal axis to create an exterior lightshelf. Although its form suggests a complex mechanism and implementation to support snow and ice loads, this research seeks to demonstrate a greater potential from both an energy and lighting standpoint.

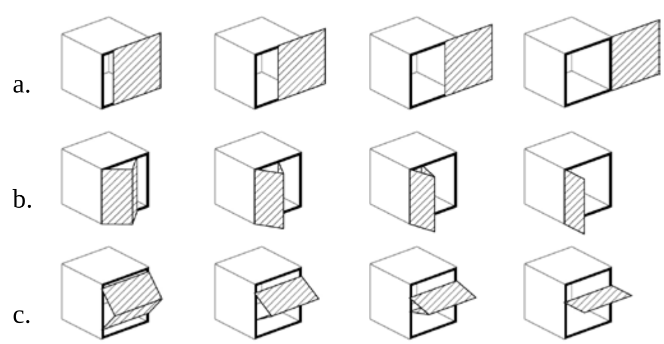

Fig. 2: Simulated positions of MIPs (a. sliding panel, b. vertical folding panel, c. horizontal folding panel)

All three forms were not optimized for energy savings nor lighting environment. The analysis of those types of MIPs proposes an exploration of the combined impact of movable elements as shading devices and of movable insulation.

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[1] Quebec City's climate is characterized by four distinct seasons and by an average temperature difference of 32 Celsius. Average (day/ night) temperature for January is -12,8 Celsius and for July is +19,2 Celsius.

2.4. Optimal scenarios and metrics

Since IES VE does not allow assigning manipulations profiles to modelled elements, meaning it cannot put into action the MIPs[2], 4 stationary positions (opening of 25%, 50%, 75% and 100%) as shown in fig. 2 are simulated over a year. An opening of 100% would show a fully open panel. Manipulation profiles are then manually constructed (7) as optimal scenarios according to two different criteria for three selected dates, i.e. summer and winter solstices and autumn equinox in sunny conditions[3]. Limits for this methodology are discussed in the conclusion (section 4).

Two metrics are used as criteria for constructing two different optimal scenarios for each type of MIP, and for each date selected in the analysis.

(1) Energy consumption per floor area (kWh/m²) compared with the reference case is used to develop an energy optimal scenario.
(2) An adaptation of the Useful Daylight Index, suggested by Nabil & Mardaljevic (8), is used to assess the lighting potential of MIPs and to develop a lighting optimal scenario. This metric (aUDI) identifies the percentage (%) of the working plane where illuminance values are between 300 and 2000 lux. This gap is considered as useful for this research. Elaborate explanation can be found in the dissertation (6).

For each hour of occupancy time (8AM-6PM), one of the four positions simulated is identified by comparing their results according to the criteria. A minimum opening of 25% is set to satisfy the need for a view an occupant would want. Energy and lighting optimal scenarios are being compared to study their compatibility since the manipulation of MIPs is considered manually controlled, and thus is open to various profiles. This comparison shows the impact of one scenario on energy consumption or on useful daylight space.

Energy savings at night time (unoccupied time, 6PM to 8AM) are afterwards added to those made by daytime. Each scenario can then be compared with the reference case and with other MIPs.

3. RESULTS

Respective optimal scenarios for all types of MIPs are, in same conditions, generally similar from an opening percentage standpoint, but result in very different energy and lighting performances.

Optimal scenarios' performances for the vertical folding MIP are shown in fig.3 through fig. 5. This particular type of MIP was chosen here because it presents the best overall performance (section 3.1). Both energy and lighting scenarios for a particular date are plotted on a single graph where the top part indicates energy consumption and the bottom part, the adapted useful daylight index, and where the dotted lines show the results of the reference case. The top gray icons illustrate the different positions of the MIP identified for the lighting scenario while the bottom black icons illustrate the positions for the energy scenario. The same shades then refer to the lines on the graph; gray for the lighting scenario and black for the energy scenario. The zone created in between the lines represents the impact of one scenario over the energy or lighting performance. For example, at 10AM on summer solstice (fig. 3), an opening of 100% compared to one of 50% results in a slight increase of energy consumption, still lower than the reference case, but also results in a much more important and desirable increase of the lighting performance.

On summer solstice (fig. 3), thermal and lighting incompatible needs are clearly shown, though not as much as for the sliding MIP (6). Indeed, an opening of 100% is suggested for the lighting optimal scenario throughout most of the day to allow a maximum light penetration while openings of 25% to 75% are identified in the energy optimal scenario form 10AM to insure shading and to avoid too much solar gains. Optimal scenarios for this date don’t present a great increase of both energy and lighting performances compared with the reference case, except in the morning when the space benefits from light reflection on the panel. Over the entire day (24 hours), the energy optimal scenario proposes an energy saving of 3,1% and an increase of 4.2% for the aUDI over the reference case. The lighting optimal scenario shows an increase of energy consumption by 4.6% and a significant improvement of the aUDI of 14.5%.

On autumn equinox (fig. 4), results show that the need for shading is greater than for summer solstice because the sun is lower in the sky, thus creating unwanted solar gains. Energy savings are obtained in the case of both energy and lighting scenarios, respectively of 27.2% and of 5.6%. Shading also benefits lighting performances by reducing high illuminance levels (potential glare). The lighting optimal scenario shows an improvement of 4.4%. The energy optimal scenario, however, decreases the aUDI by 11.1% compared with the reference case because of excessive shading. It is also interesting to note the diversity of positions for the lighting optimal scenario, thus creating diverse ambiances.

[2] However, movable insulation is dynamically simulated as the software will modify the glass thermal properties according to a profile. Thermal resistance will be added to create the effect of the presence of insulation panels.
[3] Actual dates are selected upon cloud cover and available radiation (6).

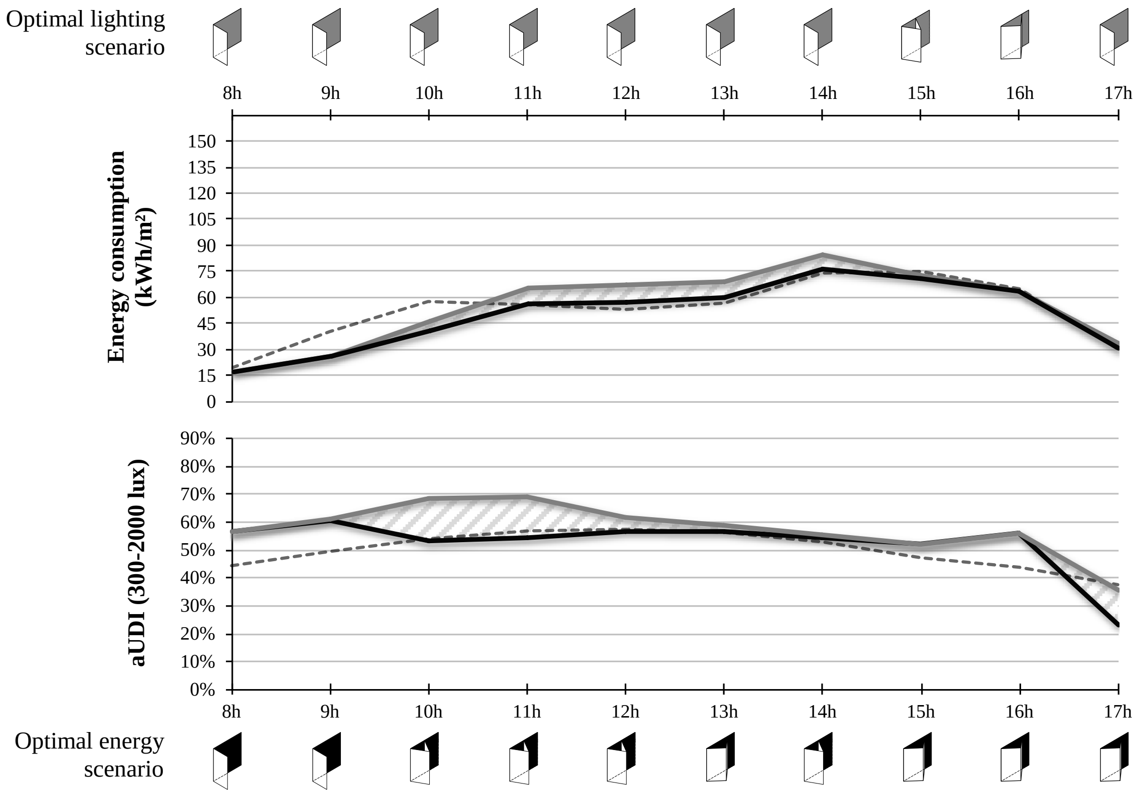

Fig. 3: Optimal scenarios, vertical folding MIP, summer solstice

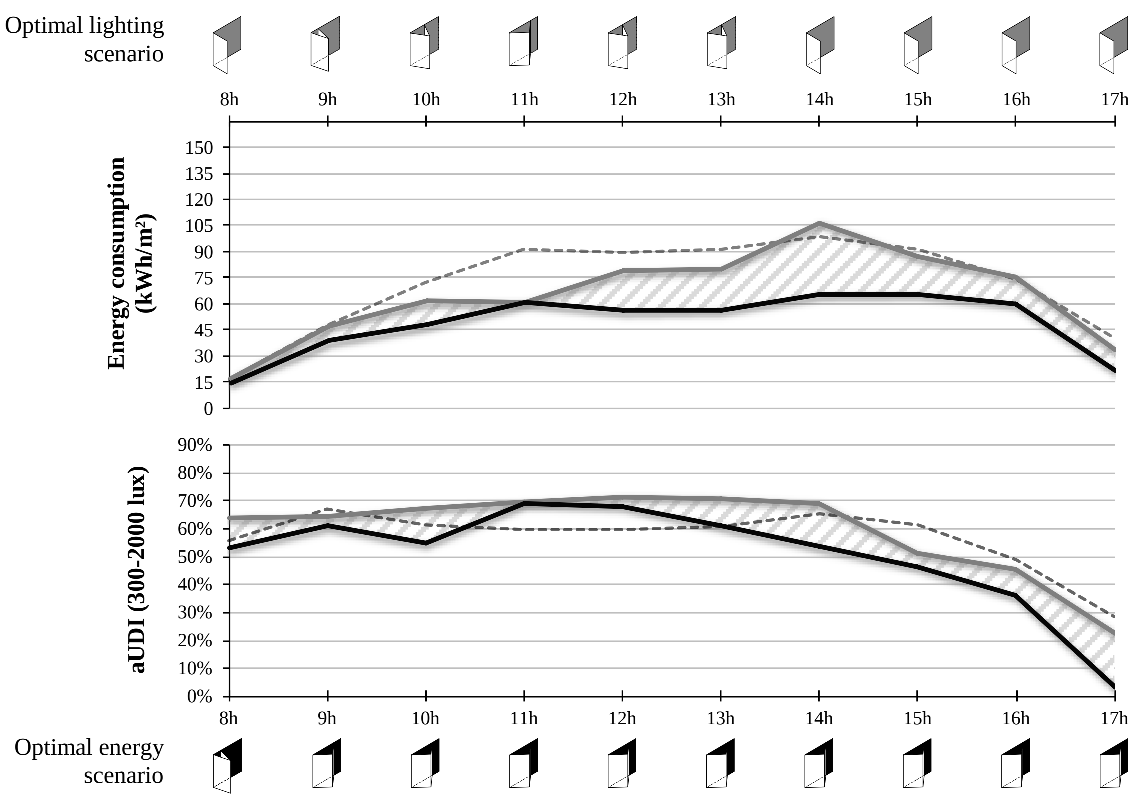

Fig. 4: Optimal scenarios, vertical folding MIP, autumn equinox

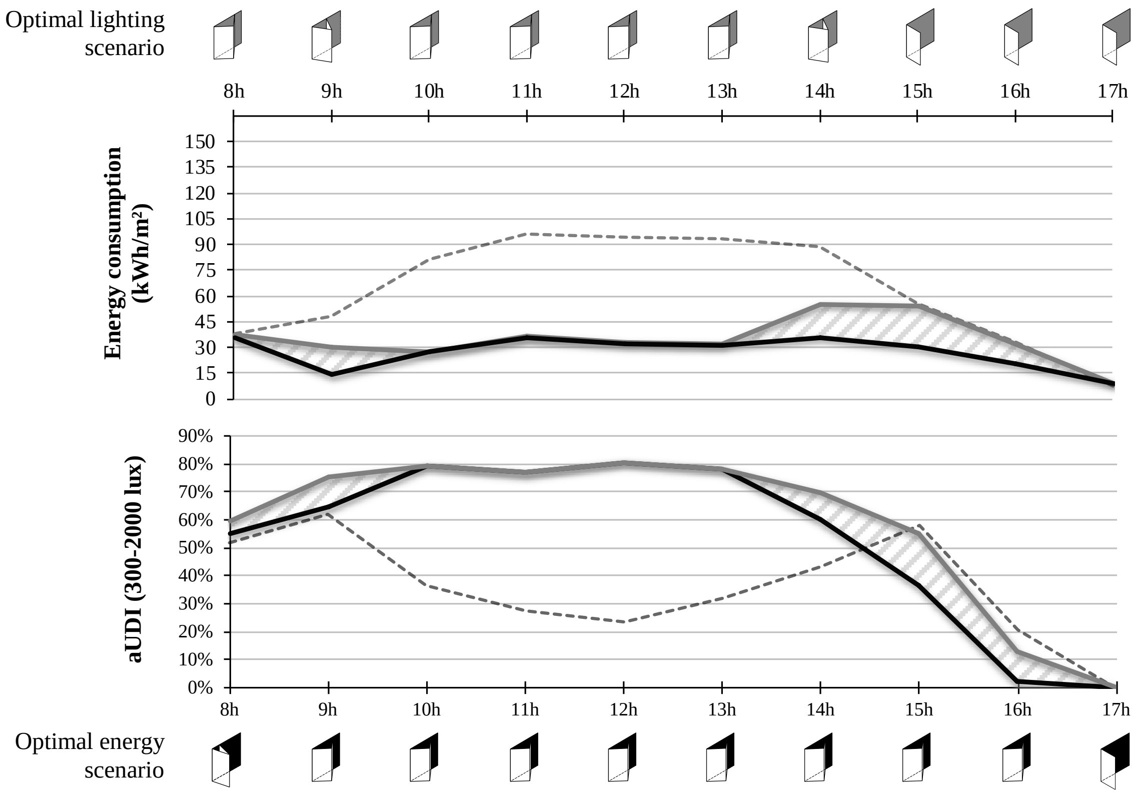

Fig. 5: Optimal scenarios, vertical folding MIP, winter solstice

On winter solstice, considerable energy savings can be obtained during night time, due to the use of movable insulation, thus greatly reducing thermal losses, but also by daytime. Indeed, there is still a greater need for shading from an energy and lighting point of view as the sun is at its lowest in the sky. Sun rays can therefore penetrate further deep in the room. The energy and lighting optimal scenarios show respectively a considerable energy saving of 41.2% and of 30.6% over the entire day (24 hours) and a lighting performance increase of 49.4% and of 64.8%.

3.1. <u>Overall performance</u>

Optimal scenarios are then compared upon their energy and lighting performances. Fig. 6 presents a graph that compiles those performances for every date and MIP, each represented by a specific icon, and where the horizontal axis indicates energy performance, and the vertical axis indicates lighting performance. The first quadrant is therefore, the quadrant of choice where an improvement of both energy and lighting performances is observed, whereas the third quadrant shows a regression of performances. The graph (fig. 6) shows that such an improvement is in many cases difficult to obtain as less than half the scenarios are in the first quadrant.

The graph (fig. 6) also clearly demonstrates the potential for the use of MIP during winter time. As said above, December scenarios considerably benefit from shading on both energy and lighting accounts. Over a 24-hour period, they also benefit from the reduction of thermal losses by night time. In fact, the latter results in energy savings of 46.5% during the unoccupied period.

As for autumn and summer scenarios, the vast majority show improvement on only one aspect. For example, autumn energy optimal scenarios, in the case of sliding and vertical folding MIPs, propose important energy savings resulting from shading, but also a decrease of lighting performance compared with the reference case. Summer scenarios show generally the worse performances.

Comparing MIP types, the vertical folding panel presents the best overall performance, as said above. From an energy standpoint, its scenarios are most of the time characterized with the best energy performance in comparison to the other types of MIPs. The sliding panel energy scenarios also show important energy performance, in some cases higher than the vertical folding panel performance. Those scenarios describe however, in many cases, the worst lighting performance. The sliding MIP’s shading is indeed very effective, but once it is fully open, the room can’t benefit

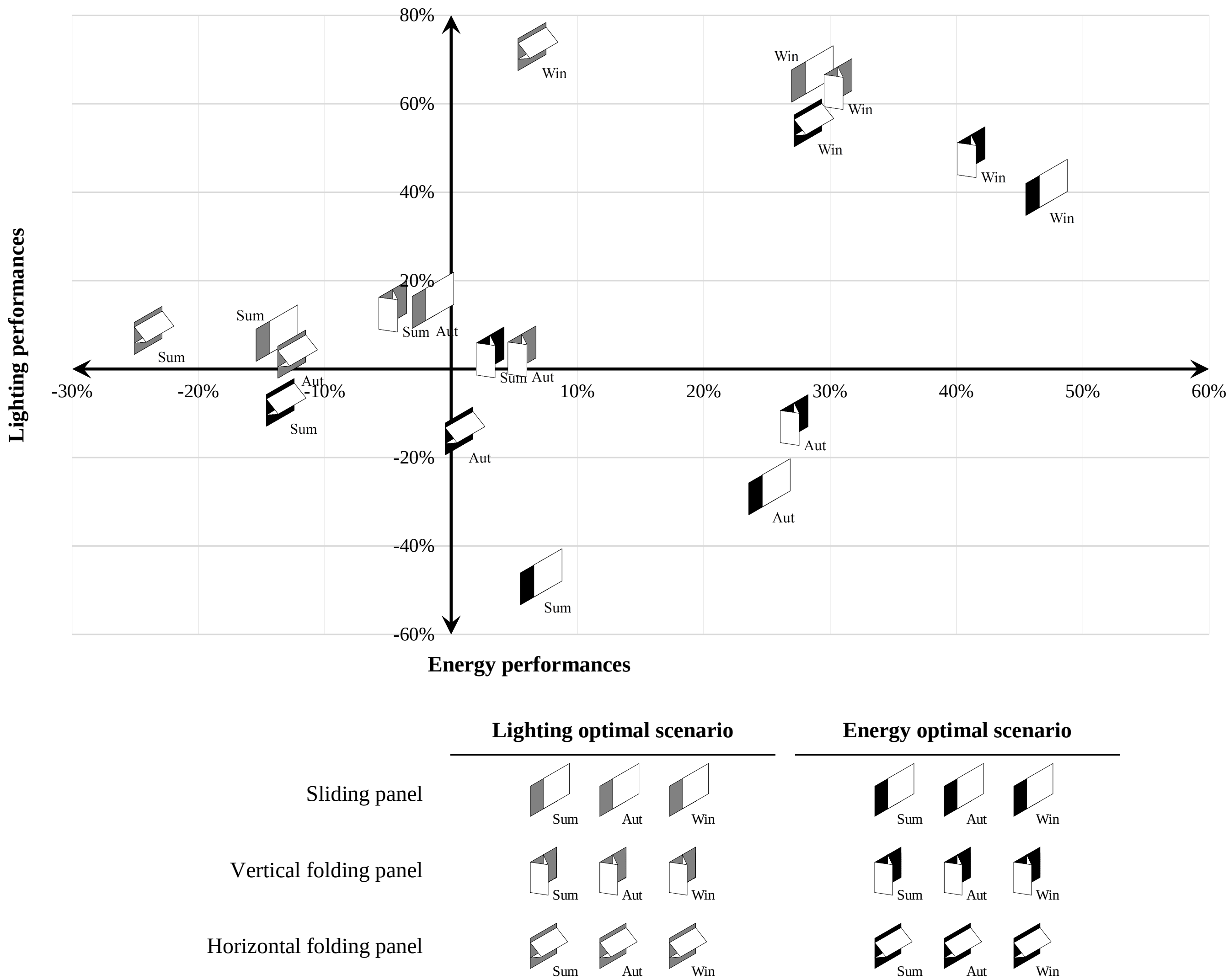

Fig. 6: Optimal scenarios energy and lighting performance for all three types of MIPs

from no shading at all. When glare would not be a problem like in summer, lighting scenarios present acceptable lighting performances but poor energy performances. It is, however, the horizontal folding panel scenarios that describe the worst energy performances compared to the other MIPs for same conditions. The height of the created lightshelf when the panel is fully open is adjusted here to permit a maximum of light reflection into the room, thus leaving an important portion of the window unshaded. Although the panel form has not been optimized, these results remain surprising and contradict a common rule that suggests horizontal shading for south oriented façades.

From a lighting standpoint, there is no clear trend. Each MIP shows an advantage over the other depending on the scenario and season. Certain types of panels can clearly be associated to a particular season according to its performances. Althoug each type of MIP can adapt its position in regard of daily and hourly conditions, results show that an adaptation of the form on a seasonal basis could be of benefit.

3.2. Compatibility index

To assess the compatibility of energy and lighting scenarios for each type of MIPs and each date, a compatibility index was developed by the author. It is calculated in two ways, by comparing opening percentage or by comparing results.

The use of two equations, detailed in the dissertation (6), shows that in some cases, opening percentages for one type of MIP and one date can be quite different while results will be similar.

The vertical folding panel scenarios describe the best compatibility index on average for the three studied dates, slightly higher than the horizontal folding panel. In fact, the vertical folding panel optimal scenarios are more compatible during June and December, while the other one presents a better index during September. The indexes for those two types of panels are twice as high as the index of the sliding panel. These results give the folding panels type a clear advantage.

3.3. Control freedom index

Another index developed by the author is used to compare the MIP's performance. A control freedom index qualifies the MIPs as an adaptive opportunity by quantifying the freedom an occupant would have to manually control the opening of a panel without impacting too much on energy and lighting performances. This index, detailed in the dissertation (6), compares the amplitude of the results obtained for the four simulated positions of a panel at each time step. That way, if the four possible positions of one panel yield similar results, it is considered that this panel gives a certain level of freedom to the occupant.

The indexes calculated for the folding panels are, like for the compatibility index, significantly higher than for the sliding panel. On average for the three studied dates, they are almost twice as high. Looking independently at each dates, the same trend as for the compatibility index is observed. The vertical folding panel shows better indexes during June and December, while the horizontal folding panel presents a better index during September.

4. CONCLUSION

The goals of this exploratory research were to demonstrate energy and lighting impact of a daily use of three forms of MIPs as shading devices and movable insulation devices on energy consumption and on illuminance control. It shows the complexity of studying movable architecture elements for predicting environmental performance. Nonetheless, this research demonstrates a clear potential for the use of MIPs, as well as introducing such devices as an effective adaptive strategy.

Results show a clear pertinence for the use of MIPs during winter time, when energy savings of up to 46% and increases of lighting performances of up to 73% are observed. The MIPs insulation characteristics play an important role during unoccupied periods as well as their shading and reflecting properties during daytime in the case of high transparency of the envelope. MIPs thus serve a triple function. They are then useful during the other dates studied when insulation by night time is not necessary. Important energy savings can be obtained during autumn equinox. Energy performances are, however, not significant during summer solstice. Increase of energy consumption is even observed in some cases. Savings are more difficult to obtain as the sun is high in the sky and as there are fewer solar gains than when the sun is lower in the sky. For the same reason, increase of lighting performance is more important in December and September. For high transparency, the shading properties of MIPs would thus be equally important as their insulation properties.

Among all types of MIPs studied, the vertical folding panel presents the best compromise between energy and lighting performances. Better performances were expected for the horizontal folding panel, but still are higher than the sliding panel's performance. It is interesting to note that implementation for vertical panels, regarding ice and snow loads, would be less complex than for horizontal panels. The vertical folding panel also yields the best compatibility index and control freedom index on average for the three dates selected, slightly higher than the horizontal folding panel. These indexes are used to assess the potential of MIPs as an adaptive strategy.

Devices such as MIPs promote adaptive interaction form occupants. This active role fosters involvement in the building performance. Occupants become inhabitants, as suggested by PLEA 2009 Manifesto (9) and Cole et al. (10). The possibility for inhabitants to adapt their environment is an important aspect of comfort (10,11). The compatibility of energy and lighting optimal scenarios as well as the freedom of manipulations a MIP allows are critical features from an adaptive comfort standpoint and can be as equally important as environmental performance. High compatibility and freedom indexes for folding panels clearly demonstrate a greater potential over the sliding panel.

MIPs can fill multiple needs for reaching comfort while reducing energy consumption. Design of such devices is part of the role architects can have regarding sustainable challenges. Furthermore, movable elements can bring to architecture a different language. In those features lies the MIP's richness.

4.1. Limits

The methodology used for this research has certain limits. Further research on the subject should be undertaken. Nevertheless, research goals were reached, demonstrating the potential of MIPs.

The main limits regard the action of movable elements within the software and the computation of certain thermal transfer processes. To overcome the fact that moving profiles cannot be assigned to modeled elements, manually constructed scenarios are made from static simulations. To narrow thermal inertia incoherence, thermal mass is reduced to a minimum and heating and cooling systems setting points are fixed and identical. Regarding thermal transfer processes, the presence of modeled panels (during occupancy period) is not taken into account in the computation of convection nor radiation. The software can simulate the presence of movable insulation by modifying the glass thermal properties. Emissivity can't, however, be modified, which can affect the reduction of thermal losses[4].

Finally, as an exploratory research, a certain amount of variables was discarded and should be subjects of further research projects, such as opening forms and orientation, glass types and comfort assessment. Extended lighting environment evaluation (13) should be undertaken as only one metrics was used for this research to explore the potential of MIPs.

5. ACKNOWLEDGMENTS

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