Adaptive Façades for Architecture:
Energy and lighting potential of movable insulation panels

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ABSTRACT: This research focuses on the performance of movable insulation panels for Nordic climates 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 the 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, adaptive architecture

INTRODUCTION

Transparency of the envelope can be considered as a 21st century essential from a sustainable architecture standpoint, for its energy benefits as well as for its biophilia features. However, in Nordic climates, windows are 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, and to occupants needs. Furthermore, MIP's manual control promotes adaptive behaviours which are considered essential in regard of environmental comfort.

Although different authors have addressed the great potential of movable insulation in reducing heat loss [1, 2], the device is not common in cold climate construction. Furthermore, no research seems to have considered movable insulation as a shading and light reflecting device.

This research proposes to combine energy and lighting analysis in the assessment of MIP's shading and light reflecting properties as well as thermal insulation properties. It analyses three types of MIPs and compares their impacts on energy consumption and illuminance level, and classifies different daily manipulation scenarios based on the panels' positions and on the ratio between energy saving and lighting control potentials. This research contributes to the exploration of adaptive façades, in regard of movable elements and their effects on ambiances. The outcomes do not provide specific optimization of energy and lighting performances of the devices. They rather aim to show the potential of movable devices and the compatibility between energy and lighting goals.

METHODOLOGY

Computer simulations were conducted for this research to facilitate comparison of the outcomes. Such simulations are largely used for this type of research owing to low-cost and to their capacity to integrate complex thermal and lighting interactions [3]. Integrated Environmental Solutions software suite (IES VE) is used in this research as 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 [4, 5]. Such a suite avoids the need to remodel within different softwares as well as possible incompatibility problems [6]. The software's characteristics and simulation parameters are fully described in a research thesis on that topic [7].

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. 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 considered as having adiabatic thermal transfers.

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 an 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.

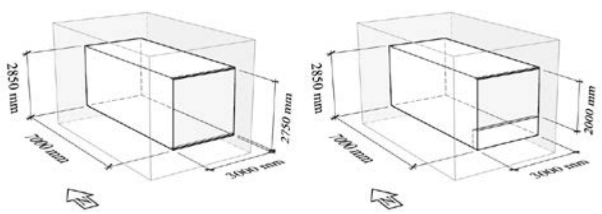


Figure 1: (left) Simulation model with use of MIPs and (right) reference case model.

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

1. A sliding panel (Fig. 2a) represents a basic system currently available on the market.
2. A vertical folding panel (Fig. 2b) folds in a vertical axis. 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 horizontal orientation asks for a robust mechanism to support snow and ice loads, this research seeks to demonstrate a greater potential from both an energy and lighting standpoint.

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.

a.
b.
c.

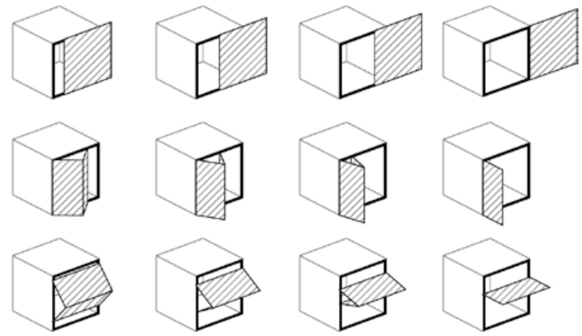


Figure 1: (left) Simulation model with use of MIPs and (right) reference case model.

Since IES VE does not allow assigning manipulations profiles to modelled elements (e.g. it cannot put into action the MIPs), 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 represent a fully open panel. Manipulation profiles are then manually constructed [8] as optimal scenarios according to two different criteria for three selected dates, i.e. summer and winter solstices and autumn equinox in sunny conditions. Limits for this methodology are discussed in the conclusion.

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) is used to develop an energy optimal scenario.
2. An adaptation of the Useful Daylight Index, suggested by Nabil & Mardaljevic [9], 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 range is considered appropriate for this research. Elaborate explanation can be found in the dissertation [7].

For each hour of occupancy (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 daylighted room surface.

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.

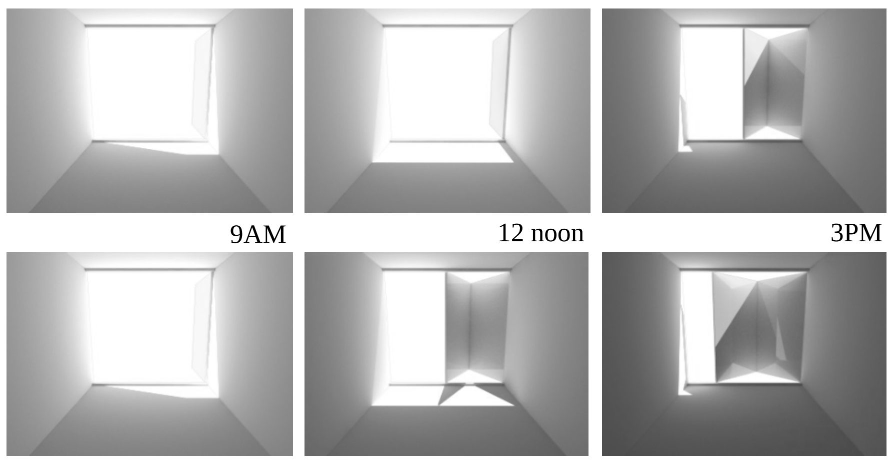
RESULTS

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

Outcomes for each type of panel are individually analysed in a qualitative and quantitative way. Renderings at 9AM, 12 noon and 3PM for both energy and lighting optimal scenarios are used to compare lighting ambiances and to analyse quantitative results. Fig. 3 shows renderings for the vertical folding panel on June 21st. In the morning, reflexions on the fully open panel generate a better light distribution in the room. While folding, top and bottom openings are created at the hinge and can illuminate the interior surface of the panel, thus softening visual contrast between interior and exterior. It also reduces the amplitude between the energy and lighting scenarios although their respective renderings still show different goals on energy and lighting accounts.

Fig. 4 shows the results for the vertical folding panel on summer solstice. Thermal and lighting incompatible needs are clearly shown, though not as much as for the sliding MIP [7]. 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, 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) in the case of the lighting optimal scenario with an improvement of 4.4%. On winter solstice, significant energy savings can be obtained during nighttime, 46.5% over the unoccupied period, 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, penetrating 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%.

Lighting optimal scenario



Energy optimal scenario

Figure 3: Interior renderings for the vertical folding panel optimal scenarios.

Both energy and lighting scenarios results, for each typical day, are plotted on a single graph (Fig. 4) where the top section indicates energy consumption and the bottom section, 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. 4), 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.

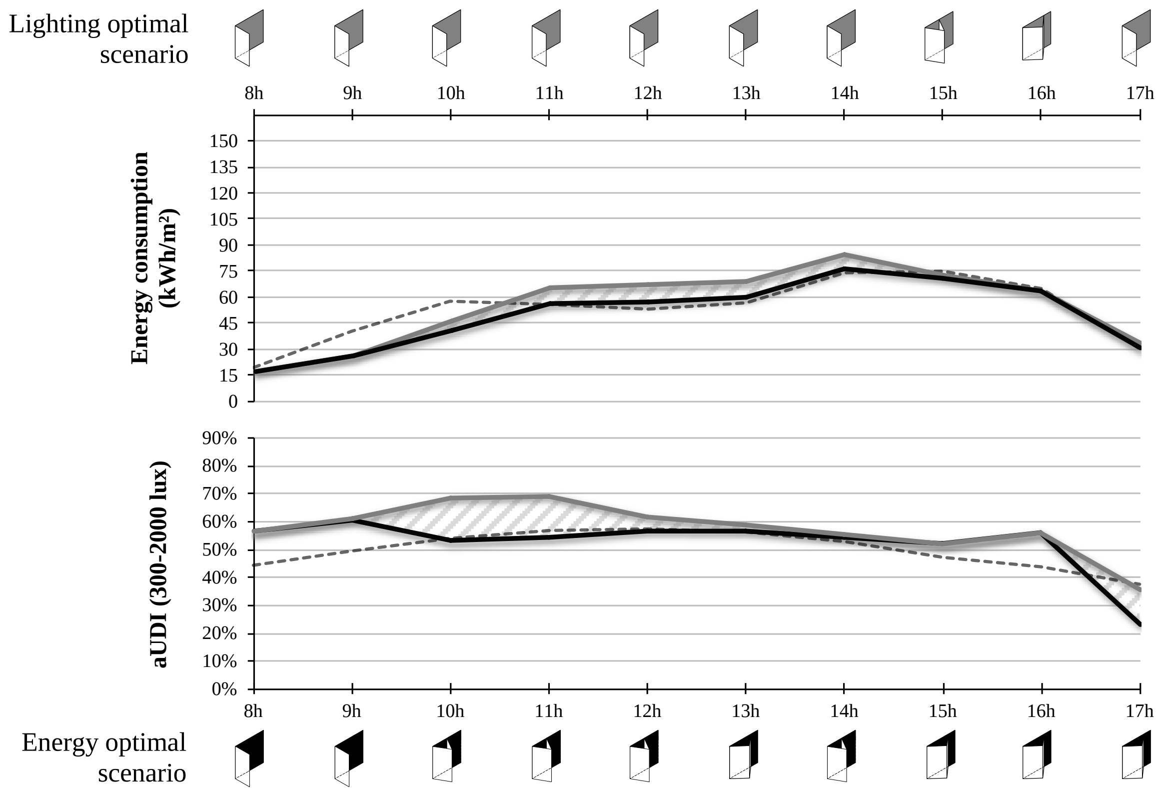


Figure 4: Optimal scenarios results for the vertical folding panel on summer solstice.

Optimal scenarios are then compared on the basis of their energy and lighting performances. Fig. 5 presents a graph that compiles those performances for each typical day and MIP where the horizontal and vertical axis respectively indicates energy and lighting performance. The first quadrant is therefore the quadrant of choice where an improvement of both energy and lighting performances is observed. The graph (Fig. 5) 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. 5) also clearly demonstrates the potential for the use of MIP during wintertime. As previously mentioned, December scenarios considerably benefit from shading on both energy and lighting accounts and from the reduction of thermal losses by nighttime. As for autumn and summer scenarios, the vast majority shows improvement on only one aspect. For example, in the case of sliding and vertical folding MIPs, autumn energy optimal scenarios propose 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. 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 show however, in most cases, the worst lighting performance. The sliding MIP's shading is indeed very effective, but once it is fully open, the room cannot benefit 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 show the worst energy performances compared to the other MIPs for the same climatic conditions. The height of the resulting light shelf is adjusted 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 puzzling 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 relative advantages over each other depending on the scenario and season. Certain types of panels can clearly be associated to a specific season according to its performances. Although 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 beneficial.

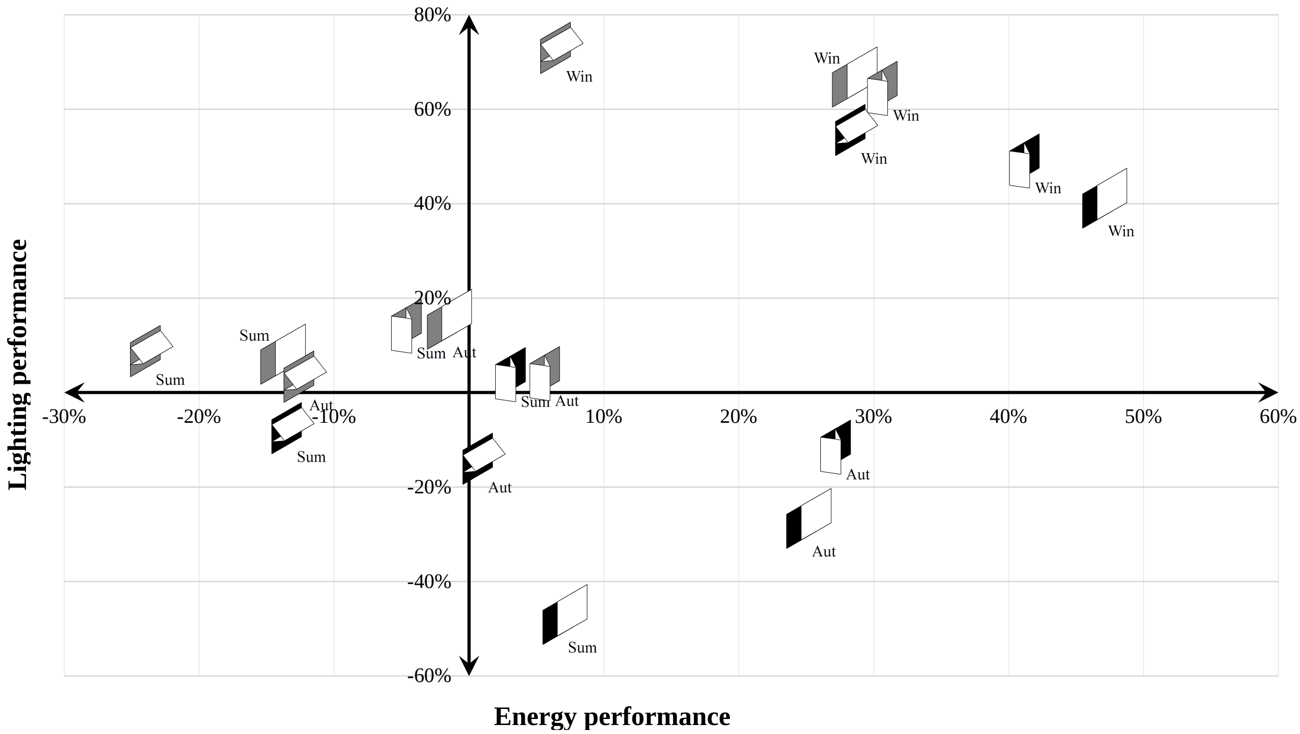


Figure 5: Optimal scenarios energy and lighting performance for all three types of MIPs

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 by comparing results and is detailed in the dissertation [7]. The vertical folding panel scenarios describe the best compatibility index on average for the three seasonal days, 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.

A control freedom index is used to qualify 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 [7], 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. 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. Compatibility and freedom indexes, twice as high as for the sliding panel, give the folding panels type a clear advantage.

CONCLUSION

The goals of this exploratory research were to demonstrate energy and lighting impacts of a daily use of three types of MIPs as shading and movable insulation devices on energy consumption and on illuminance control. The 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 wintertime, 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 summer and fall when insulation by nighttime 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 due to high sun altitude and as there are fewer solar gains than when the sun is lower in the sky for other seasons. 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 seasonal days, slightly higher than the horizontal folding panel. These indexes are used to assess the potential of MIPs as an adaptive strategy.

Easy to use 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 [10] and Cole et al. [11]. The possibility for inhabitants to adapt their environment is an important aspect of comfort [11, 12]. 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 control 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. The design of such devices clearly belongs to architects in close collaboration with mechanical engineers as they have significant effect on the overall performance of a building. Furthermore, movable elements can bring to architecture a dynamic dimension expressing its aim at adaptive behaviour of the inhabitants.

The methodology used for this research has certain limits. 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. Further research on the subject should be undertaken to address those limits.

Finally, as an exploratory research, a certain amount of variables was discarded and should be subject of further work, such as opening forms and orientation, glass types and comfort assessment. Extended lighting environment evaluation should be undertaken as only one metrics was used for this research.

ACKNOWLEDGEMENTS

This research was conducted within larger research projects, “The Creative Eye: a digital process exploring visual and thermal diversity in architecture” funded by the Fonds québécois de recherche sur la société et la culture FQRSC 2008-2012 and “Adaptive Architecture: experiencing visual and thermal delight in architecture” funded by the Social Sciences and Humanities Research Council of Canada SSHRC 2009-2013.

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