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Electrochromic glazings: dynamic simulation of both daylight and thermal performance

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Abstract

Electronically tintable glazings have now reached maturity and are part of the options to be considered in the design of energy-efficient dynamic facades, both in renovation and for new buildings. However, to assess concretely the impact of such solutions, it is necessary to carry out dynamic simulations and to consider simultaneously thermal and daylighting performance.

This approach, which until now required the use of several distinct specialized tools, is now available with a single software and can be initiated at the earliest stages of design. This paper presents the new simulation possibilities offered in the last release of the DIAL+ software, and show how the tool provides a new effective way to quickly quantify the potential of electrochromic glazings regarding energy, daylight and comfort targets.

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Keywords: Electronically tintable glazings, Daylighting & Thermal analysis, Early design stage

1 Introduction

1.1 Context

The constant evolution of energy performance requirements over the last few decades has led to the design of buildings that are increasingly energy-efficient in terms of heating requirements. One of the consequences of this trend is that buildings are more and more sensitive to the risks of overheating, including in mid-season. In addition, taking into account the visual comfort of the occupants and, in particular, the control of glare in the workplace, places solar protection at the heart of designers' concerns. At the same time, daylighting and views have been shown to be beneficial for people's health and well-being in most building types [1]. In this context, the maturing of electronically tintable glazings (electrochromic or EC glazings), which visual and solar properties can adapt to external changing conditions while being always transparent, offers new and exciting opportunities, both in renovation and new buildings. The assessment of the contribution of this new technology is complex, however, insofar as it requires a dynamic evaluation of the thermal and light effects associated with this technology.

DIAL+ is a software dealing with the optimization of the building envelope, based on a room scale analysis [2]. Until now, the daylighting analysis was focused on Daylight Factor calculation and Diffuse Daylight Autonomy

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(Radiance [3] simulations). Three-Phase method calculation [4] has been implemented in the last release (v2.5) in order to take into account the dynamic properties of EC glazings as well as automated blinds. For thermal analysis, we ran dynamic thermal simulation with the “Cooling” module of DIAL+ [2].

2 Input process

2.1 *Glazing / Shading device selection*

EC glazing is a novelty in the pallet of sun shading devices insofar as the glazing and the mobile protection are only one. During the current input process, the user has to select between the following glazings types: *Reflecting*, *Tinted*, *Clear*, *Diffusing* and *Electrochromic (EC)*. In the event that EC is selected, no other mobile sunscreen will be considered in the next steps of the input process.

2.2 *Number of control zones*

Some of the existing products available on the market are proposing a multi-zone control of a given glass pane (up to 3 zones) [5]. Thanks to the DIAL+ interface, the user can easily choose the most suitable configuration and adapt the dimensions of the different control zones.

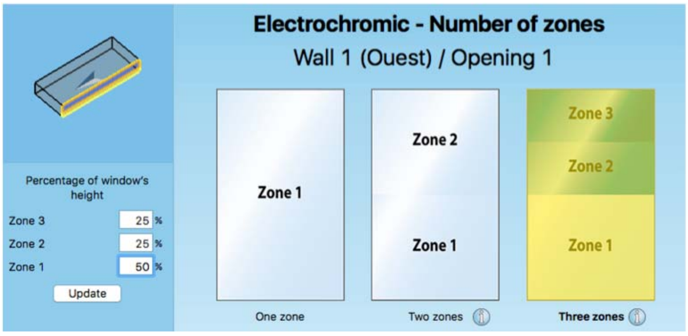

Fig. 1: Screen copy of the interface dealing with the description of the number of zones of the EC glazing.

2.3 *Swithching thresholds*

EC glazings offer several intermediate states (up to 3) between “Clear” and “Fully Dark” states. For each state, the software proposes default sets of values for both visible transmission and g-value. In addition, threshold values are proposed to switch from one state to the other. These values are based on the incident flux on the façade and are expressed in illuminance (lux).

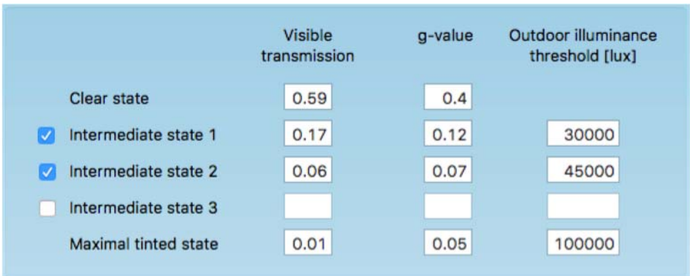

Fig. 2: Screen copy dealing with the selection of visible transmission and g-value of the EC glazing, as well as threshold values

2.4 *Control strategy*

There are two main modes of control of the EC glazings:

- The "*Daylight*" mode is used to activate intermediate tinted states. This mode is useful to accompany the slow variations of the daylight and makes it possible to limit the risks of glare related to intermediate skies. It is only controled with the incident illuminance on the façade.
- The "Glare" mode is dedicated to preventing the risk of glare in particular due to direct sun and reflections, and uses the darkest state of the glazing. When activating this mode, the user has to describe a specific area where sun rays are prohibited during the defined hours.

2.5 *Case study*

To illustrate the performance analysis related to the implementation of EC glazings, we described a medium-sized landscape office (width: 18.3m; depth: 7.75m; height: 2.88m) with one external west-oriented glazed façade (the other walls are internal). The window to floor ratio is 16% (glazed area). The reflection coefficients of the room are as follows: floor: 0.30, vertical walls: 0.50, ceiling: 0.70. Visible transmission and g values of EC glazing for each state are shown in Fig. 2, the Uvalue = 1.1 W/m^{2}K.

The thermal parameters are as follows:

- Thermal mass: Concrete slab with subfloor, lightweight walls, 16 cm insulated façade, raw ceiling (concrete).
- Mechanical ventilation (no window opening): 8AM-6PM: 36 m^3/h.pers.; 6PM-8AM: 3m^3/h.pers.
- Heating devices: radiators (P_{max}= 14.1kW).
- Cooling devices: In order to see the influence of the electrochromic glazing on solar gains and indoor temperature profiles, we did not put any cooling device. In addition, there is no natural ventilation.
- Setpoint temperature: Tmin= 20°C.
- The simulations were run with climatic data of the city of Lausanne [6].

3 Simulation process

3.1 Daylighting

To evaluate the daylight potential of EC glazing, it is necessary to carry out a simulation for each hour of the year, in order to take into account the adaptation of the glass transmission characteristics according to the meteorological data. To this end, we implemented in DIAL + the Three-Phase method resolution model [4]. The process is as follows:

- Determination of sun protection status: for each hour, the software determines if there is sun and what is the outdoor illuminance on the façade. According to the thresholds described by the user (see Fig. 2), the status of the EC glazing is then pre-calculated.
- Construction of matrices for the sky, the external masks and the interior of the room: in order to speed up the simulation process, the flux transfer is calculated into the following three phases for independent simulation:
  1. Sky to exterior of fenestration
  2. Transmission through fenestration
  3. Interior of fenestration into the simulated space
- Hourly calculation: For each hour a simulation is performed to calculate the direct and diffuse components entering the room.

3.2 Thermal aspects

The dynamic simulation of the thermal behavior of the room, which allows to know the evolution of the internal temperature as a function of heat gains and losses and thus, to estimate the heating and cooling loads, is also based on hourly simulations. At each time step, the program adapts the energy transmission factor of the glazing according to the incident radiation and the control characteristics chosen by the user (see Fig. 2).

4 Results

4.1 Daylighting

As first result of the daylighting simulation, DIAL+ displays a map of the average annual daylight illuminance on the workplane (see Fig. 3). It is also possible to display the illuminance values for specific hours (see Fig. 4).

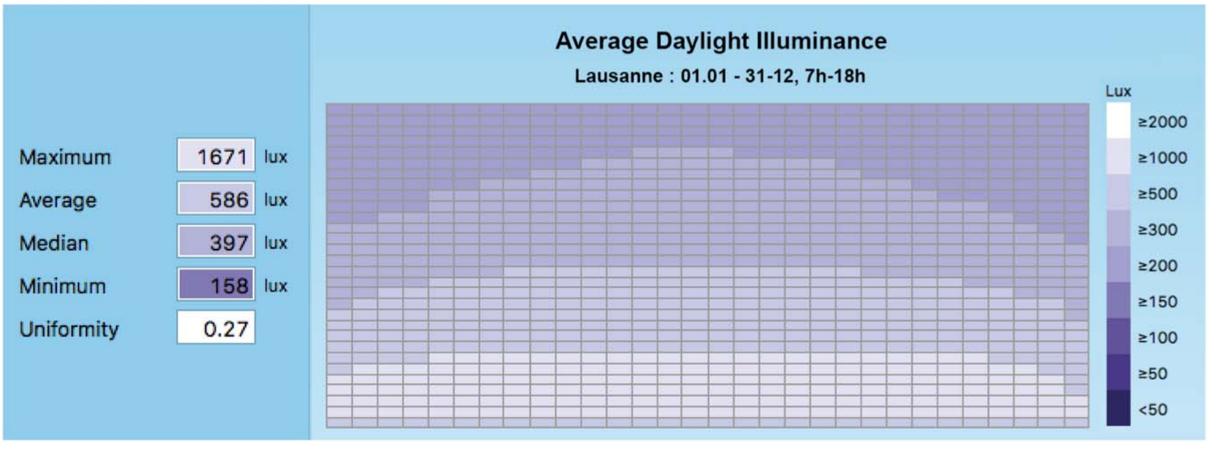

Fig. 3: Average annual illuminance on the work plane (h= 0.80 m): West oriented room equipped with EC glazings (1 zone / daylight mode)

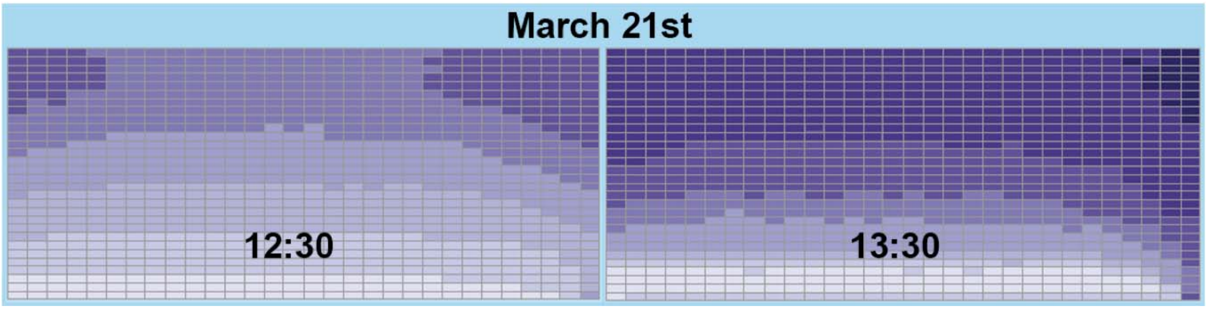

Fig. 4: Illuminance values on the work plane (h= 0.80 m) for 2 consecutives hours on the 21st of March (1 zone / daylight mode)

In this example, we see that at 12:30 there is only diffuse light on the facade and the glazing is in clear phase. At 13:30, the sun hits the façade and the EC pane is tinted to limit glare, which ends up with some reduction of daylight availability.
Temporal maps of the different tint states can be displayed (see Fig. 5). They are useful for checking the functioning of the system and make it possible to better analyze the results of the simulations.
Daylight and Glare modes can be activated separately (left part of Fig. 5) or jointly (right part of Fig. 5).
In this example, we can see that when the “glare mode” control is ON, the “fully dark” state is activated as soon as the sun hits the façade, which prevents any glare risk. The same type of temporal maps can also be displayed to control the status of “classic” shading devices as venetian blinds or fabric devices.

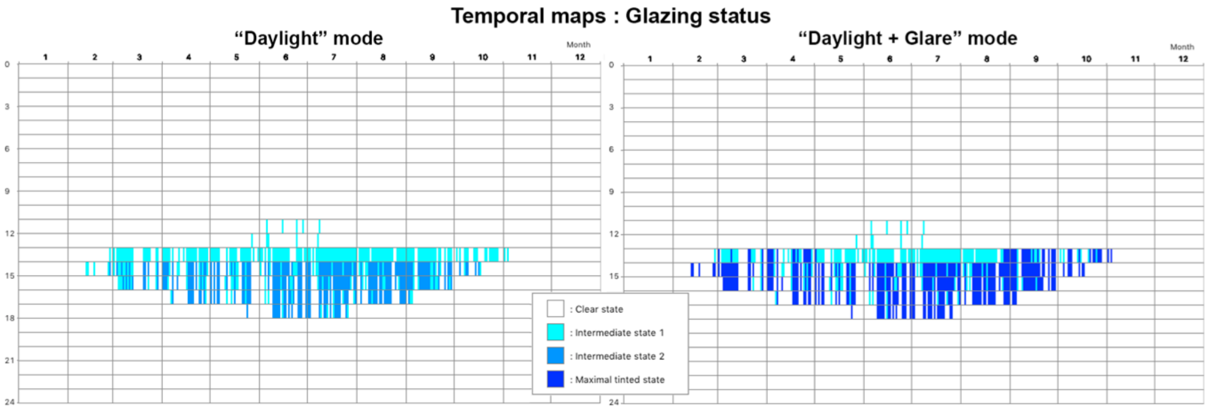

Fig. 5: Temporal map showing the glazing status during the year according to the control strategy (one zone).
(Left = “Daylight” mode / Right = “Daylight + Glare” mode,).

Temporal maps also allow the user to have an overview of the annual average illuminance in the analyzed room, as shown in Fig.6. On the right part of this figure (Glare mode = ON), it is possible here to easily identify the moment when the glazing is in the "Fully dark" mode.

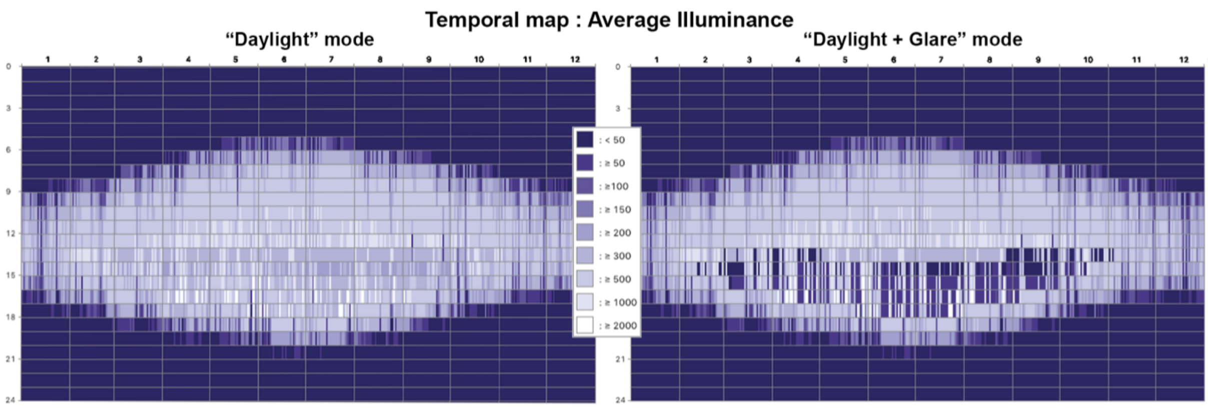

Fig. 6: Temporal maps showing the average illuminance during the year according to the control strategy
(Left = Daylight mode / Right = “Daylight + Glare” mode).

Since the simulation is performed on an hourly basis, it is also possible to calculate the Dynamic Daylight Autonomy, as shown in Fig. 7. Results can be adjusted as a function of the occupancy schedule, and the illuminance requirements. Other results, such as Spatial Daylight Autonomy (sDA) or Useful Daylight Illuminance (UDI), are available and can help positionning the room performance with regards to environmental labels [7].

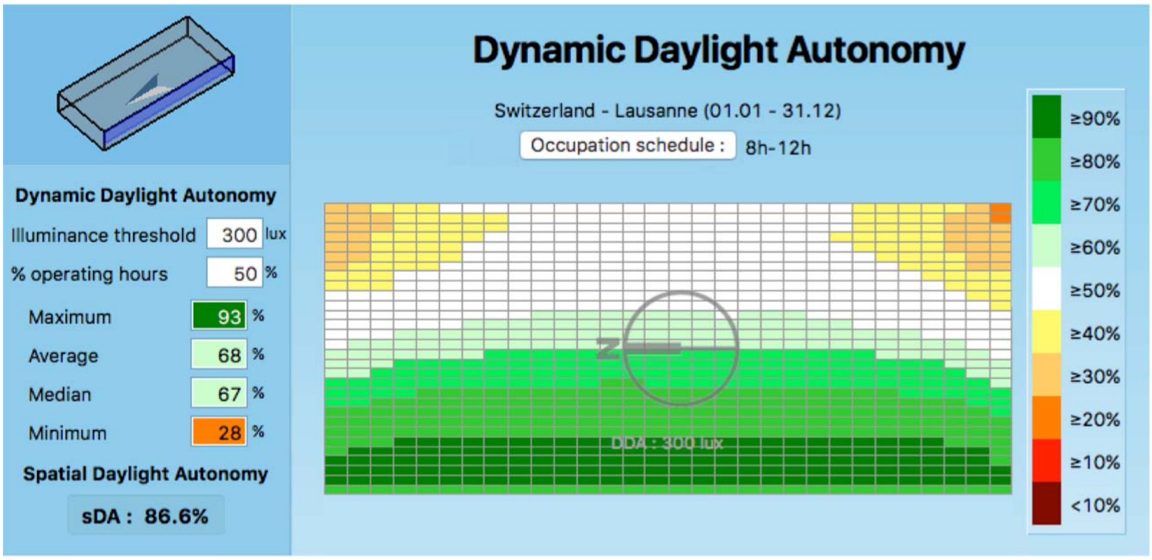

Fig. 7: Dynamic Daylight Autonomy and Spatial Daylight Autonomy on the work plane of a west oriented room equipped with EC glazings (Work plane height = 0.80m, 1 control zone / daylight + glare mode).

4.2 Thermal aspects

One of the advantage of EC solutions lies in the fact that the solar factor of the glazing varies more or less in proportion to the light transmission, which makes it possible to control the solar gains. The last upgrade of DIAL+*Cooling* (thermal module) allows to take into consideration dynamic g-values and thus, to calculate for each time step, the actual energy gains due to EC glazings according to the control strategy (the software has been validated with regards to ISO-13791, EN-15265, EN 15255 [8]).
Among the results provided by the software, one can mention annual profiles of indoor temperature (air, sensible and surface temperature), solar gains for each window and heating and cooling loads.
Fig. 8 shows an example of the results obtained with two different shading solutions, namely:
- Brown line: Clear glazing (Tv=0.8, g=0.62, U_g = 1.1 W/m^{2}k) with outdoor automated venetian blinds; which corresponds to a *standard* solution that guarantees good performance in terms of daylighting and solar gain control (g_{tot}=0.09 according to Griesser VSR 780 [9]).
- Green line: EC in *daylight* mode (Clear state: Tv=0.59, g=0.40; Intermediate state 1: Tv=0.17, g=0.12; Intermediate state 2: Tv=0.06, g=0.07, Fully tinted state: Tv=0.01, g=0.05; Uvalue = 1.1 W/m^{2}K).

On the left part of Fig. 8, we can see how solar gains are managed during four consecutive summer days. It can be seen here that EC glazings solution induces a greater reduction of the transmitted solar gains than the solution with automated blinds. This is due to the fact the EC glazing shows a lower g-value in comparison to the standard case in the clear mode (0.4 vs. 0.62), and a quite similar g-value in the tinted mode (0.07 vs. 0.09)

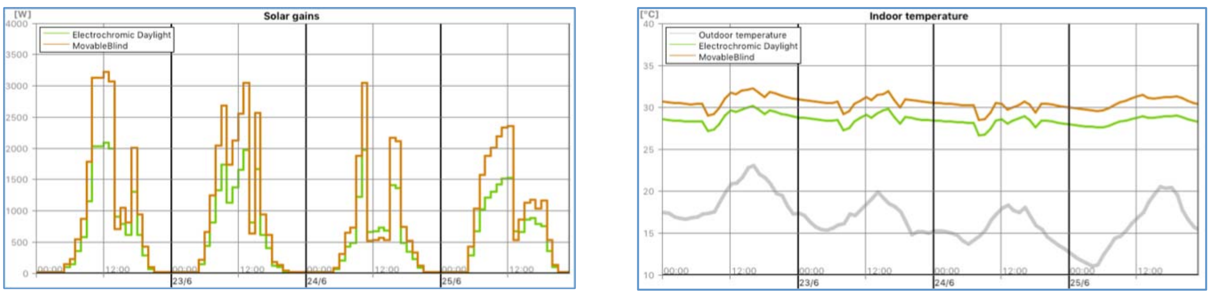

Fig. 8: Example of thermal evaluation of a West oriented room equipped with EC glazings during 4 consecutive summer days.
Left: Solar gains profiles Indoor temperature profiles

On the right side of Fig. 8 we can see the impact on indoor temperature profile during the same period (22-26 June). In this case, the average reduction in temperature is about 3°C (this difference could have been less significant if a more selective glazing or a different management of the electrochromic control thresholds had been used for the comparison).
Another difference between the two solutions lies in the fact that, the views out are always preserved even with EC glazings in the darkest state, while the blinds obstruct partially or completely the views when activated.

The thermal simulation module also allows to have an overview of the comfort zone resulting of the use of EC glazing, as shown in Fig. 9 (in this particular case, natural ventilation is provided by manually opening windows during occupancy).

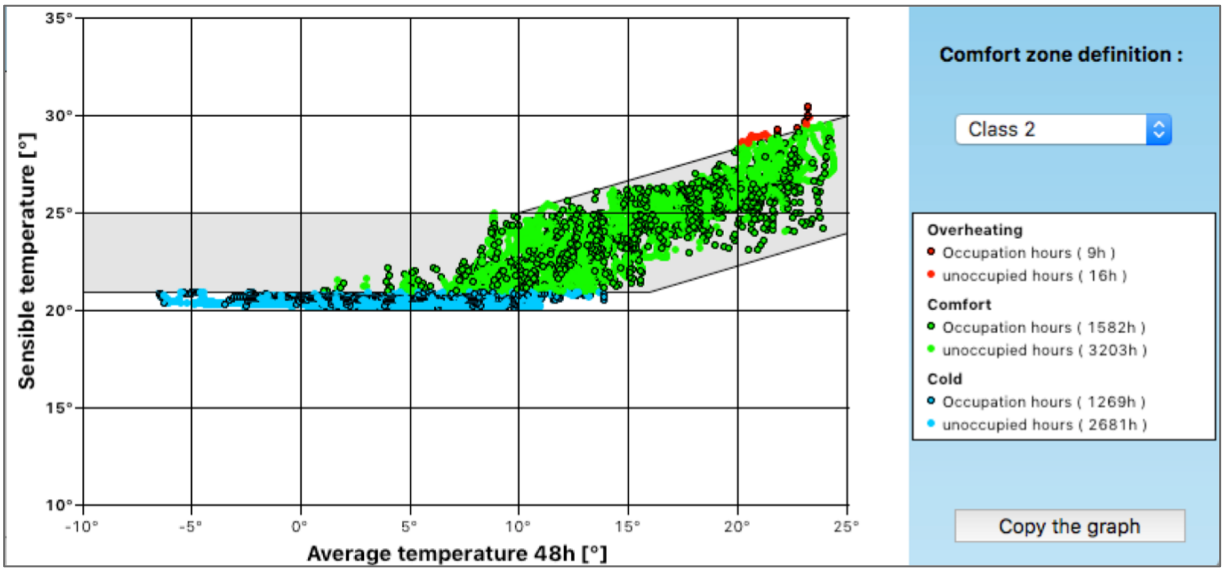

Fig. 9: Thermal evaluation of a West oriented room equipped with EC glazings
(One zone / *daylight* mode / manual opening of the windows during occupied hours), Comfort zone Class 2 according to EN 15251.

5 Conclusions

This quick overview of the new functionalities of DIAL+ shows that it is possible to evaluate from the early design phase the performance of dynamic systems such as EC glazings. The opportunity to perform a simultaneous analysis of the daylighting performance and the thermal behavior of a given room allows the designers to make an informed decision. We believe this offers new insights into the use of this emerging technology and will facilitate its implementation in projects where it is particularly suited.

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