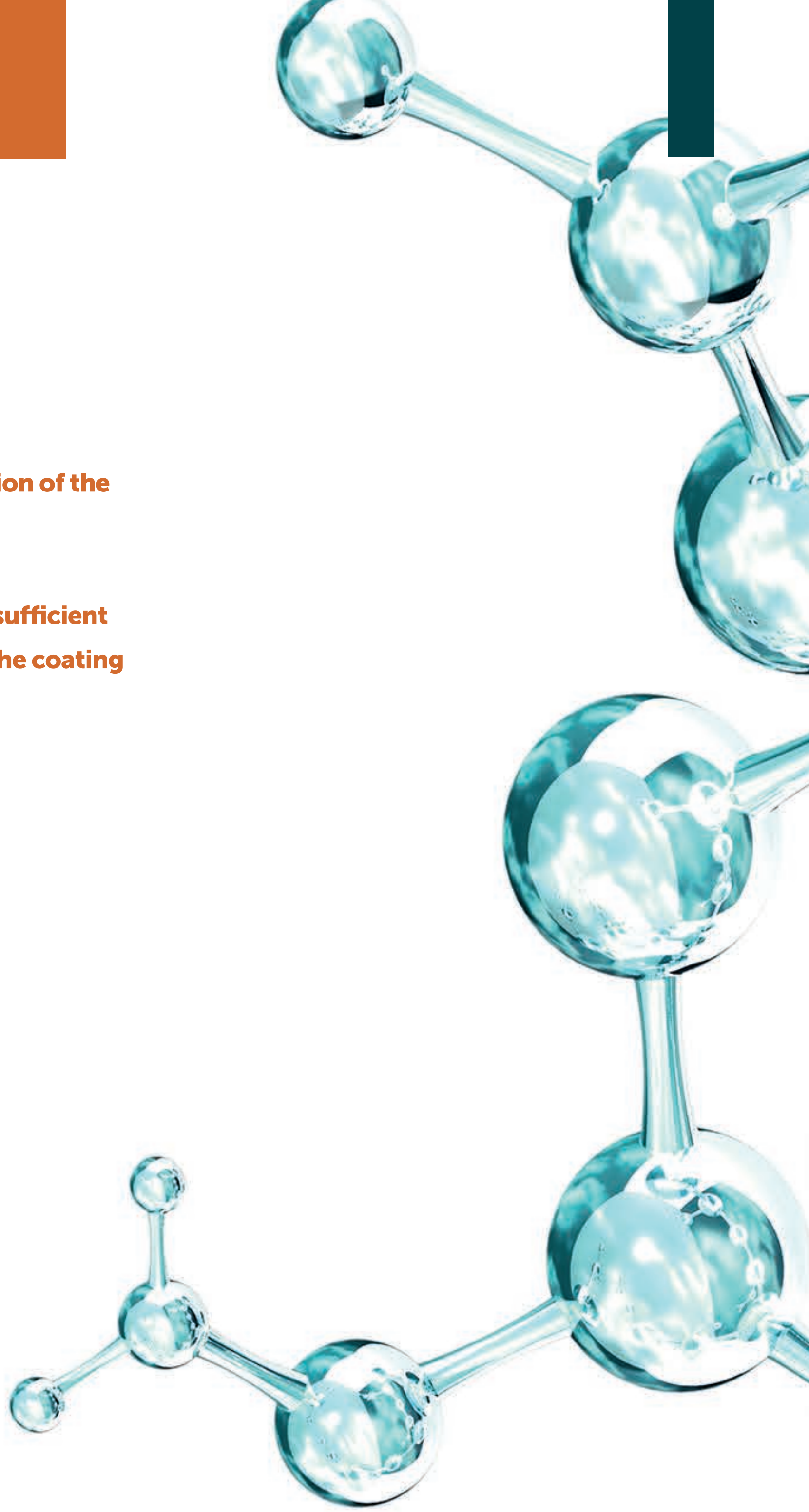
A technical paper

Influence of coatings on the perception of the anisotropy phenomenon

Contents



Influence of coatings on the perception of the anisotropy phenomenon

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Abstract

Since the dissertation of Saverio Pasetto (2014) on the appearance of anisotropy in heat treated glass, a lot of efforts have been made to minimize the visibility of anisotropy on façades.

On-line measurement equipment has been developed, an official standard ASTM C1901-21e2 was published but all of this is related to only the monolithic heat treated glass. However, most heat treated glass is further processed into laminated glass and/or insulating glass units (IGU). One important factor to consider is the influence of the post temperable coatings on the optical retardation and as such on the anisotropy of the finished glass product.

The interaction of the inner pane with the outer pane of an IGU is more important when coatings with low outside light reflection and a high light transmission are used. Measurements combined with a survey, where people graded the level of anisotropy, allow us to link the optical properties of a coated glass with the appearance of anisotropy. Further work needs to be done to predict the effective level of anisotropy of the finished unit based on the optical retardation measured on the single heat treated glass and the type of solar control (reflective) coating used.

Keywords: 1. Anisotropy 2. Post temperable coatings 3. Optical retardation
4. Light transmission / Outside light reflection

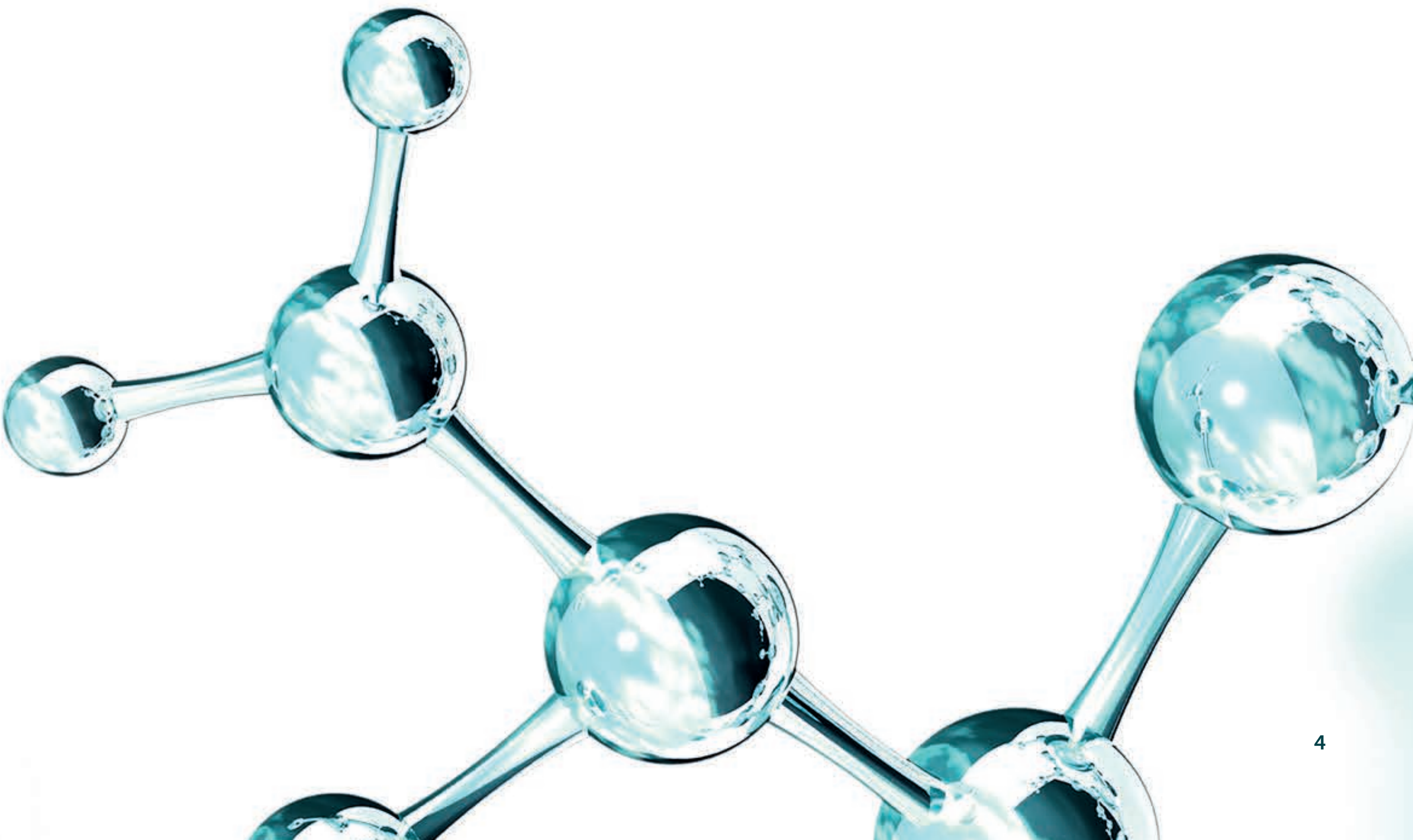
Introduction

A phenomenon of growing importance

Architects are always looking for perfectly flat glass in their façade, where no optical distortion or color variations are visible. Although roller-wave, overall bow and edge lift are well known phenomena limited by the standards, the situation is different with anisotropy. The same standards which regulate maximum allowable optical distortion, are accepting anisotropy as inherent in all heat-strengthened and fully tempered glass.

Although anisotropy is a physical phenomenon, its appearance is not generally accepted. Actual specifications are trying to limit the appearance of anisotropy on the façade. The conclusions of the dissertation “Anisotropy as a defect in U.K. architectural float heat-treated glass” by Saverio Pasetto made this clear. [1] Since then a lot of efforts have been made by the glass industry to minimise the visual appearance of anisotropy. A visualization method has been developed allowing to improve the homogeneity of the heating and cooling of the glass during the heat treatment process by modifying the settings of the tempering oven parameters. A quantification based on the photo-elastic theory allows calculation of the optical retardation. [2] All of these developments have resulted in the ASTM standard C1901-21e2 [3] and the Technical Note FKG 01/2019. [4]

One of the further actions mentioned in the dissertation of Saverio Pasetto is: “Investigate how coatings and multiple glass build-up in insulated glass units and laminated glass units (and their combination) influence the visibility of anisotropy”. [1] In this paper the influence of coatings in a multiple glass build-up is examined.



1.0 Measuring is necessary, but not sufficient

Several equipment manufacturers have developed in-line scanners. These allow processors to measure the optical retardation of each piece of heat treated glass coming out of the tempering line.

As such, the equipment operators receive real-time information on the level of anisotropy of each single heat treated glass. This enables them to adjust the tempering furnace parameters if necessary.

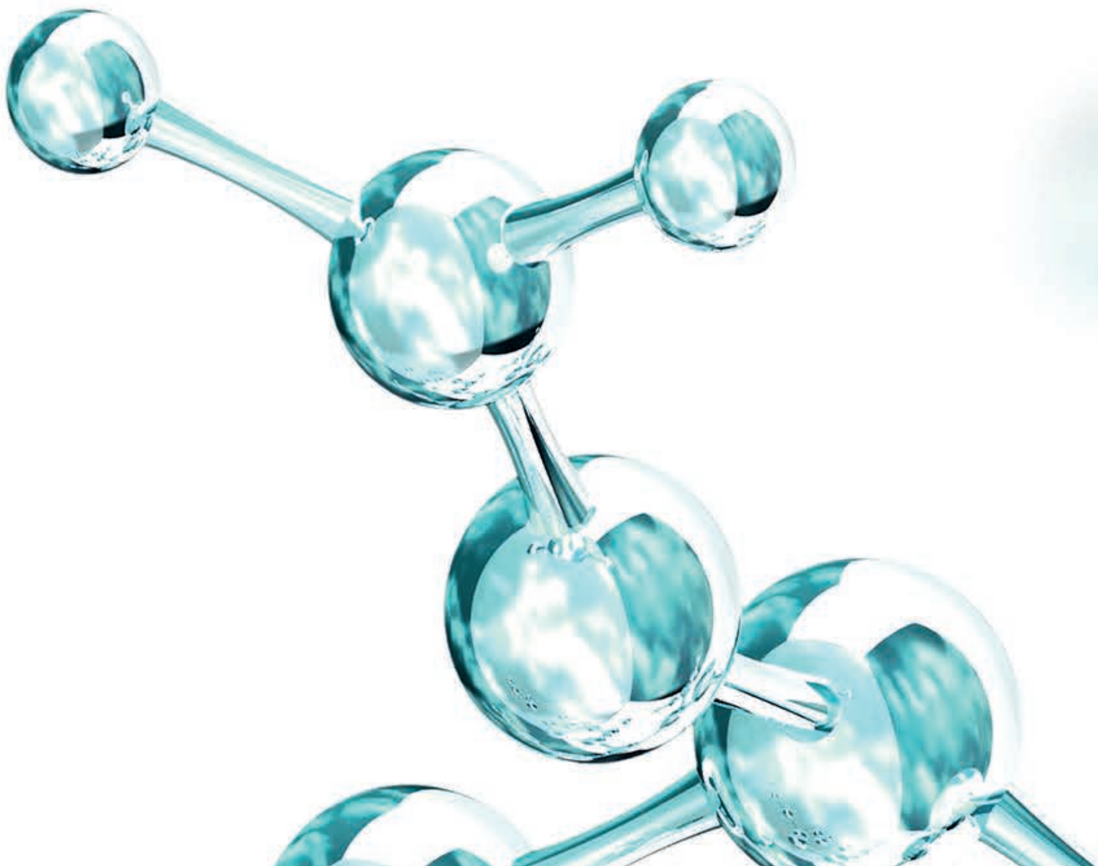
Although the in-line scanners allow considerable improvement in the homogeneity of the appearance of each single heat treated glass, they still don't allow us to predict and limit the visibility of the anisotropy of the finished insulating glass unit (IGU) or answer the real questions: What is the influence of the solar reflective coating? Will the coating mask the anisotropy of the inner pane of the IGU? Or will the inner pane, with or without a thermal low-E coating increase the level of anisotropy of the outer pane?

2.0 Perception greatly depends on the coating properties...

A survey was organized among people of different backgrounds i.e. sales & marketing, technical people, R&D and so-called specifiers who have daily contacts with architects.

The goal of the survey was to classify different coated glasses in the following way:

- Five samples per coating type were produced - each of them with a different tempering quality (i.e. from low level of optical retardation up to high level).
- The to-be-tempered coatings were all solar reflective coatings (i.e. typically put on surface #2 of the IGU).
- The main differences between the coatings were the visible light transmission VLT and the outside light reflection LRo.
- The samples were classified from 1 to 5 - rating them from 1 being "very good" with a uniform appearance of anisotropy, to 5 being "bad" with strong visibility of anisotropy. Consequently, a coating classified as class 3 is deemed average and considered as the threshold of being acceptable on a façade.



The specific observation conditions were:

- Incident light is polarized at 70% in the vertical p-direction
- The samples are positioned at an angle of 45°
- The angle of observation is 60°, close to Brewster's angle

Additionally, white balance was respected to take the photographs. These conditions were chosen to mimic a realistic worst case scenario as could happen in natural conditions outside.

The following coatings were fully tempered:

Coating type	LT (%)	LRo (%)	Glass type	Glass thickness (mm)
1.	0.57	0.18	Standard float	6
2.	0.67	0.16	Standard float	6
3.	0.77	0.13	Standard float	6
4.	0.82	0.12	Standard float	6
5.	0.52	0.16	Standard float	6
6.	0.67	0.14	Standard float	6
7.	0.77	0.11	Standard float	6
8.	0.54	0.27	Standard float	6

Table 1: *Solar control reflective coatings used for the survey to determine the criticality of VLT and LRo in the appearance of anisotropy.*

The optical retardation measured after tempering:

Class	1	2	3	4	5
Mean optical retardation [nm]	15	23	30	35	42

Table 2: *Mean optical retardation classifying the tempered glass from "very good" – class 1- to "bad" – class 5 - in terms of visibility of anisotropy.*

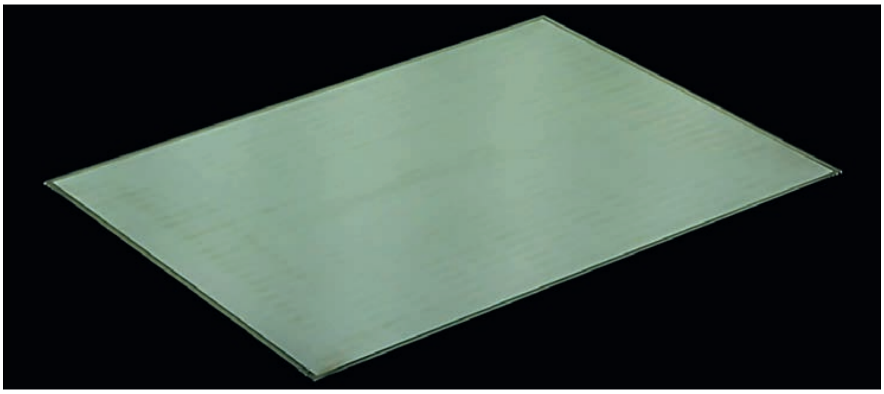
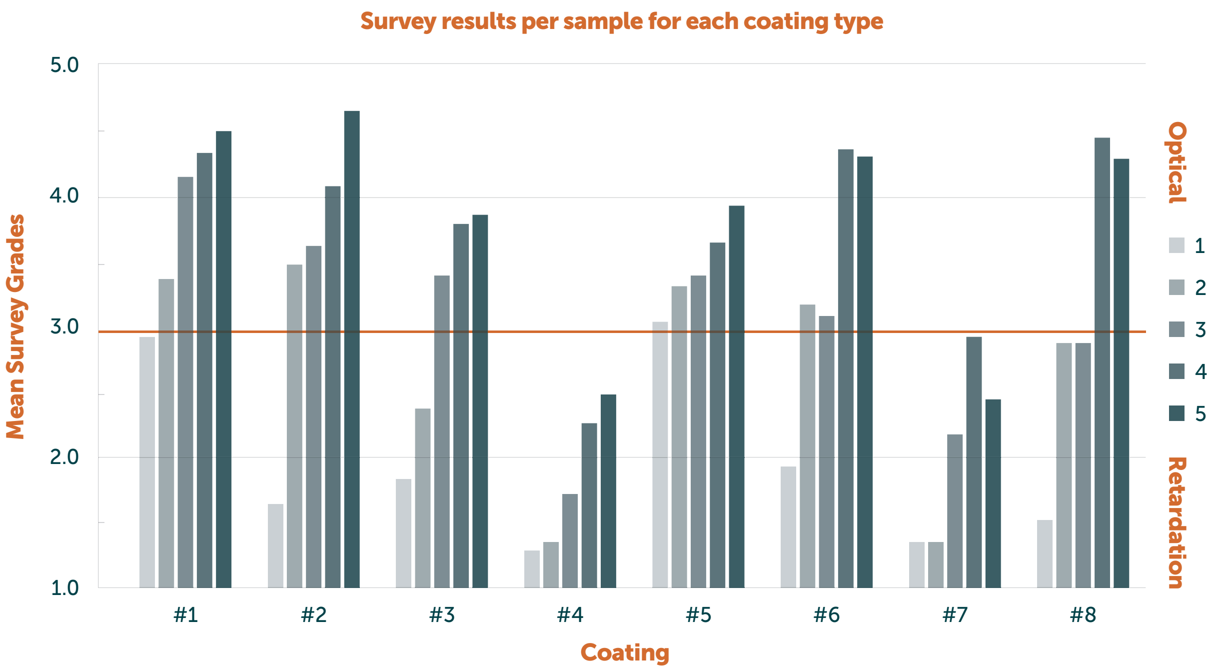


Fig. 1
Sample observed for the survey (coating type #1, optical retardation class 3).

The outcome of the survey gave the following result:



A striking observation is the difference of the answers given for the different types of products. Some coatings are always under the threshold (i.e. class 3, highlighted by a red line) and some coatings are always above.

For example, all samples of coating type #5 were given a score above 3.0, no matter the level of optical retardation that was measured with a scanner. Therefore, the respondents seem to have found the anisotropy patterns on this coating very impactful during the observation. On the contrary, the same patterns on the samples with coating #4 were not considered as highly visible, as all samples were given a score below 3.0.

This observation illustrates that the light transmission value and the external reflection factor play a role of first order in the perception of anisotropy. Indeed, if the light transmission value is low and the reflection factor is high, an important proportion of incoming light will pass through face 1 to be reflected on face 2 where the solar control coating is. The anisotropic inner stress state of the tempered glass will be revealed under the form of quench marks by the observers as they see the reflected light through the glass.

Fig. 2
Result of the survey classifying different solar reflective coatings having an identical tempering quality for their appearance of anisotropy.
Light grey - left bar = Class 1
Dark grey - right bar = Class 5

3.0 ...and the IGU composition

The outer pane of the IGU is not always the only tempered element in the final glass composition. The question is how the inner glass pane of the IGU will influence the appearance of anisotropy of the coated outer pane?

In order to understand the impact of the inner pane, new observations were made using the same fully tempered solar control glasses combined with one or more tempered inner panes. To be sure about the influence, the same uncoated or thermal low-E coated inner pane was used in combination with the different solar control glasses (see Fig. 3).

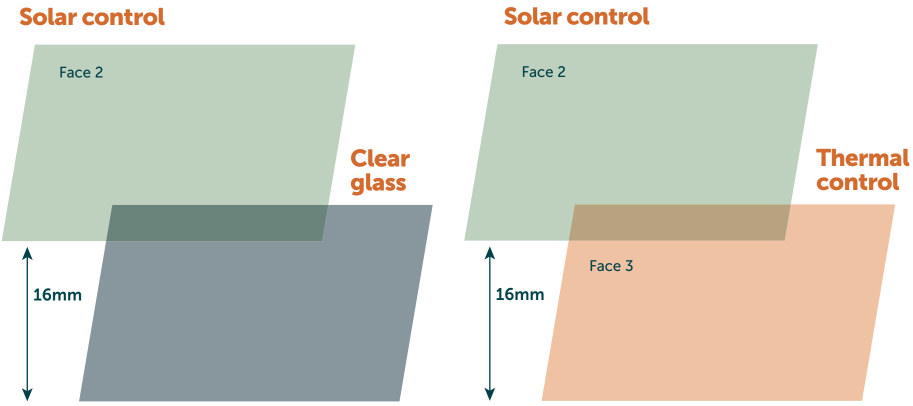


Fig. 3
Fully tempered solar control glass processed into an IGU with a clear tempered glass (left) or a thermal low-E coated tempered glass (right). All glass panes are 6mm thick.

The new observation showed that the critical monolithic solar control glass (i.e. low VLT and high LRo) is hardly or not influenced by the tempered inner pane whereas the non-critical monolithic solar control glass (i.e. high VLT and low LRo) is highly impacted by the inner pane.

A second part in the new observation combined the solar control coated glass with a tempered inner pane, both having different levels of optical retardation (see Table 2). The same conclusions could be drawn as above. Fig. 4 shows the impact of the tempered inner pane on coating #1 and coating #7 from Table 1.

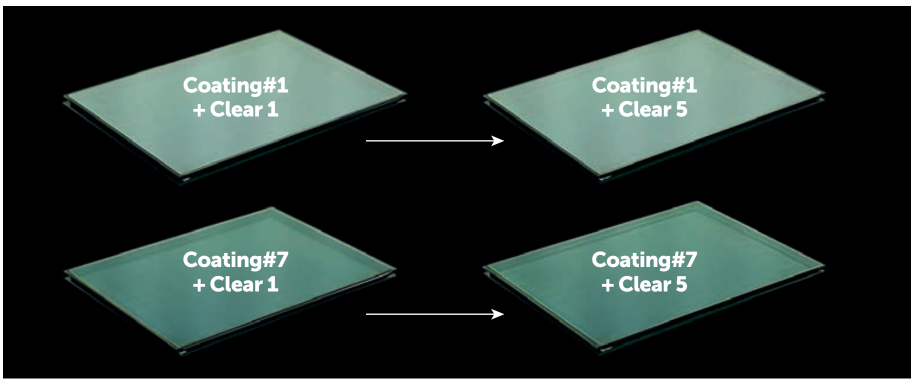


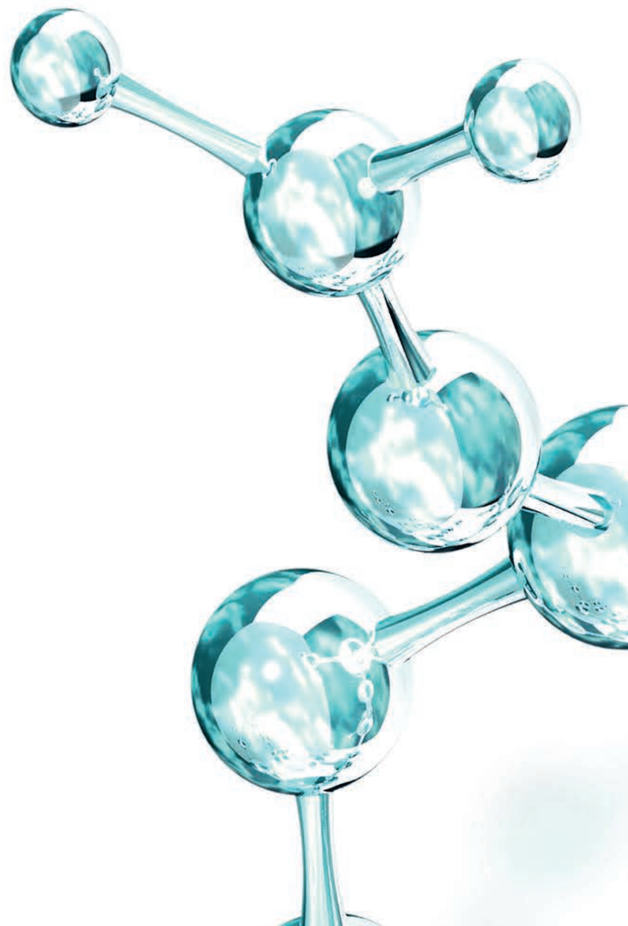
Fig. 4
Solar control glass coating combined with a "very good" and a "bad" tempered inner pane. The observation conditions are the same than for the observations of monolithic glass (see 2).

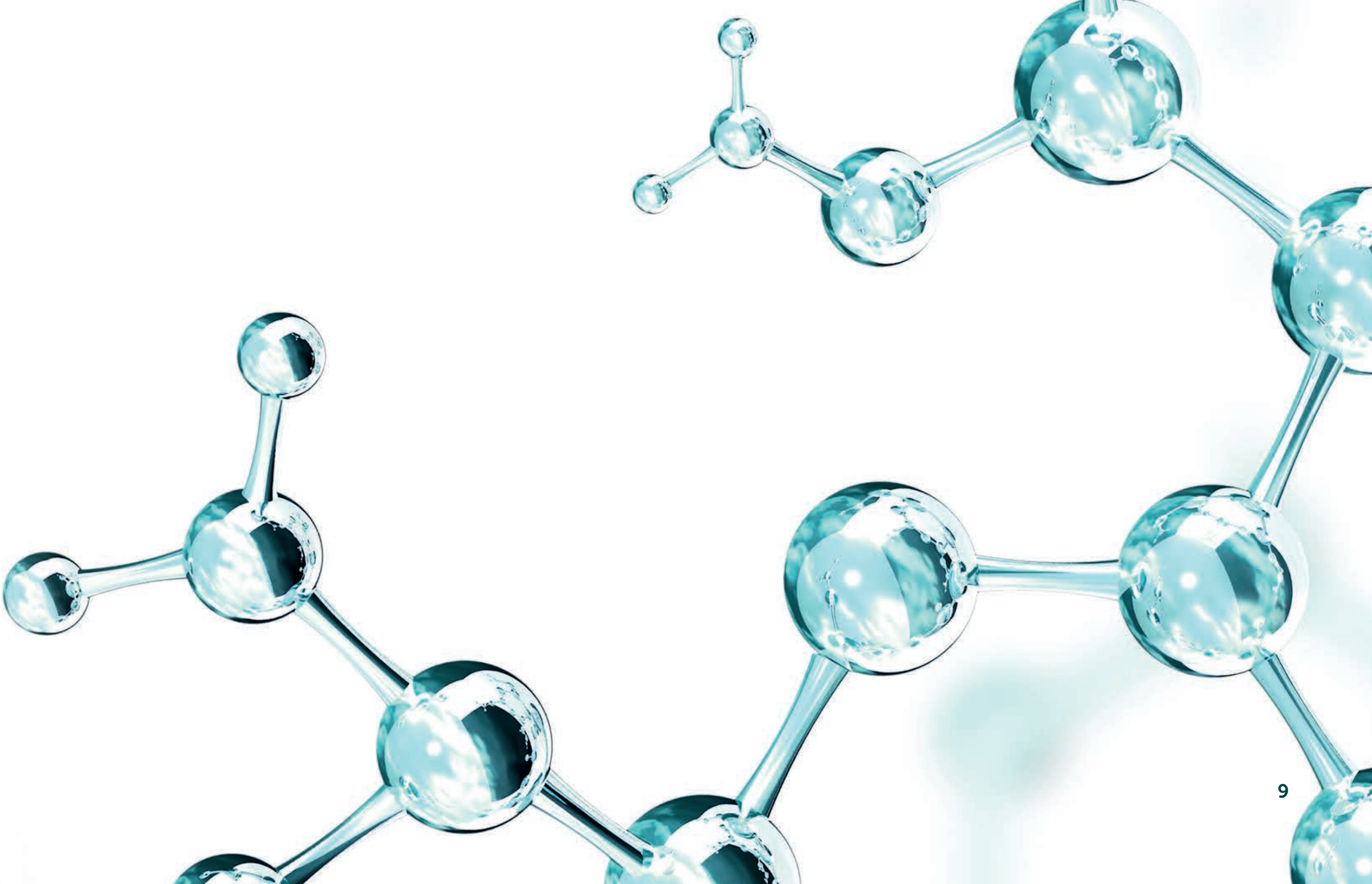
Finally, the same exercise was repeated in a triple glazing composition.

The glass pane in the middle is often annealed or heat-strengthened. When annealed, observations showed that the presence of this middle pane resulted in a less severe impact of the inner pane (in comparison to double glazing compositions) on the overall aesthetics due to the lower overall light transmission through the IGU.

When heat-strengthened glass is used as a middle pane, the conclusions for triple glazing units remain the same as for a double glazing unit. The middle and inner panes have a more or less severe impact depending on the criticality of the solar control coating.

For non-critical monolithic solar control coated glass (high VLT and low LRo), the combination with heat treated middle and inner panes can lead to high visible anisotropy patterns. In this case, the tempering of all glass panes of the IGU is critical. On the contrary for critical monolithic solar control coated glass, the heat treatment of the external glass is very critical as this outer glass pane (coating) will hide the inner and eventually the middle glass pane.





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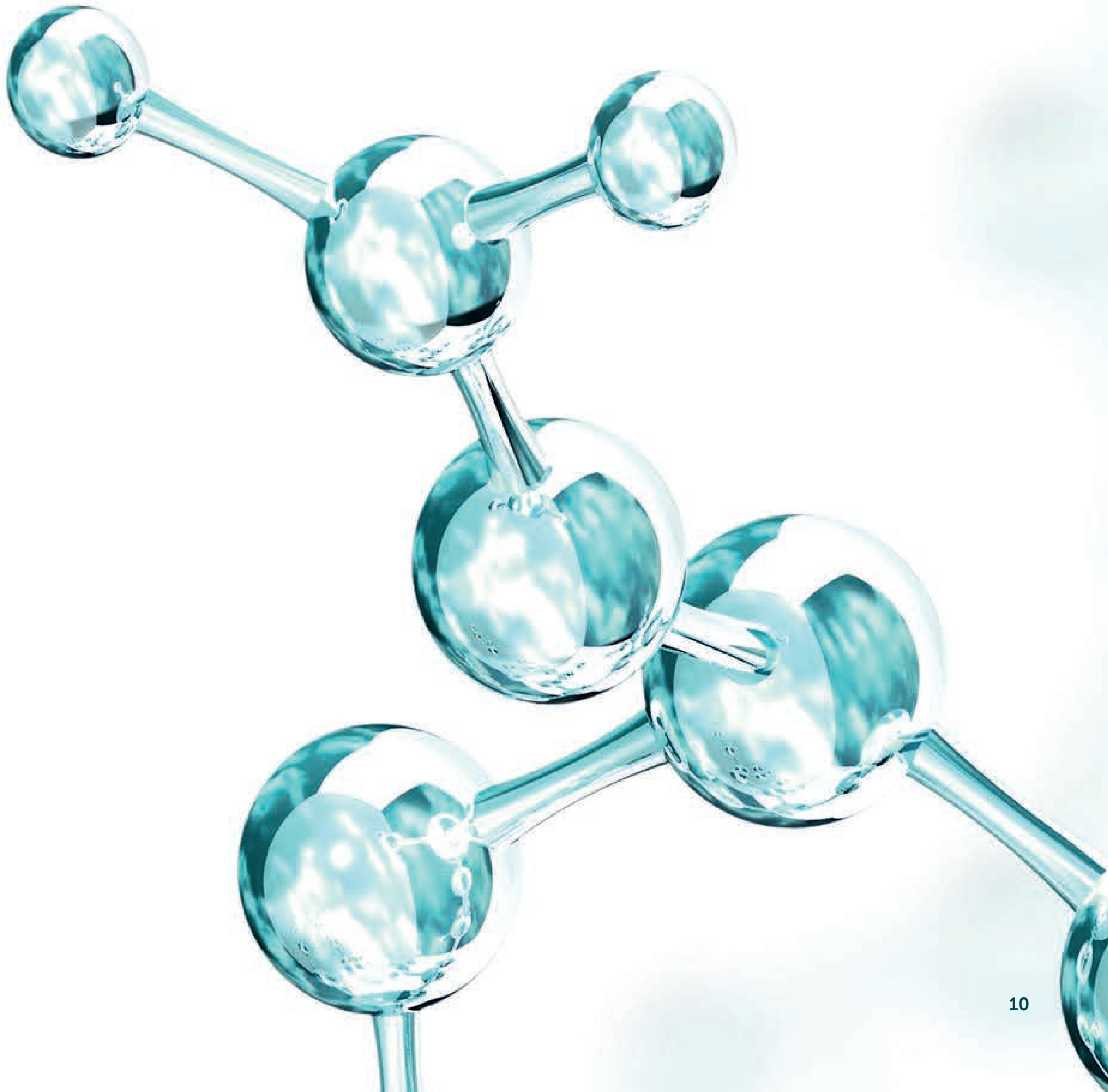
Conclusion

In-line scanners allow to optimize the tempering process making the anisotropy more uniform i.e. less visible. But this is applicable only for the single heat treated glass and doesn't give any information on the appearance of the finished insulated glass unit.

The outcome of a survey showed that the coating has a major influence on the appearance of the finished unit. Solar control reflective coatings with a high light transmission and low outside light reflection are showing less anisotropy for a same optical retardation. On the other hand, these solar control coatings are more sensitive to the quality of the tempering of the inner pane.

In short, high light transmittance and low outside light reflectance are critical for further processing whereas the appearance of anisotropy of a low light transmittance and a high outside light reflectance coating is hardly influenced by the quality of tempering of the inner pane of the IGU. So depending on the chosen solar control reflective coating, the assembly into an IGU becomes more or less critical. Hence simply limiting the optical retardation of the single heat treated glass doesn't guarantee a certain level of anisotropy of the finished IGU.



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