Chromogenic Glazing: Performance and Durability Issues as addressed in IEA Task 27

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Introduction

Chromogenic glazing, characterised by the property of variable transmittance, is able to respond appropriately to varying external environments, so that its potential for improving the visual and energy-saving conditions in buildings is greater than conventional glazing. It clearly falls within the scope of "advanced windows" being studied within Task 27 of the IEA Solar Heating and Cooling Programme. Within Task 27, the performance and durability of chromogenic glazing are being investigated in Projects A2 and B2, respectively. As the industrial production processes for this glazing are still being developed and refined, it is too early for its environmental impact to be studied in detail in Subtask C, but initial approaches have been suggested.

The aim was to focus on chromogenic glazing which is either already on the market or where prototypes are close to market introduction, rather than laboratory samples, and to address issues that are important for the application as architectural windows. Only electrochromic and gasochromic glazing is being studied within Task 27. Manufacturers of chromogenic glazing based on thermotropic or polymer-dispersed liquid crystal materials were also approached initially, but have not yet decided to participate.

Participants

Manufacturers and research institutes from Europe, the USA and Japan are represented among the participants in projects A2 and B2 on chromogenic glazing. The participants in these two projects and their activities within Task 27 are indicated in Table 1. Many of the participants are involved either in the SWIFT project (Switchable Facade Technologies) supported by the European Union [1] or in projects funded by the U.S. Department of Energy [2], so that the Task 27 group can draw on information beyond that obtained only by its formal participants.

Country	Organisa-tion	Production /sample prepara-tion	Optical measure-ment	Optical / thermal modelling	Building simulation	User studies	Test rooms/ outdoor exposure	Accelerated ageing tests / modelling
France	CSTB		x				x	x
	EDF				x	x		
	Saint-Gobain	electro-chromic	x					
Germany	FH Aachen		x	x	x	x	x	
	FLABEG	electro-chromic	x				x	
	Fraunhofer ISE		x	x	x	x	x	x
	Interpane	gaso-chromic	x	x			x	x
Italy	ENEA	x	x		x	x	x	
	SSP		x					
Japan	Asahi Glass	x	x					
Netherlands	TNO			x	x			
Sweden	SP							x
	Uni. of Uppsala			x	x			
	Vattenfall			x	x			
USA	Gentex	electro-chromic	x				x	x
	LBNL	gasochro-mic/electro-chromic	x	x	x	x	x	
	NREL		x				x	x
	SAGE	electro-chromic	x					
	Uni. Mas-sachusetts			x				

Table 1: Participants and activities concerning chromogenic glazing within Task 27 [3].

Performance of Chromogenic Glazing

Laboratory characterisation

Different approaches are being followed in parallel within Task 27 to characterise the performance of chromogenic glazing. The simplest of these is to determine those properties in the laboratory which are usually specified for conventional glazing, for each different transmittance state of the glazing. Even with this "simple" approach, the fact that variability is an intrinsic property of the glazing means that the specified properties depend on the choice of operating parameters (see review of recent literature in [4]), even before possible ageing processes have had an effect. As the glazing characterised in Tables 2 and 3 is generally at least at the prototype stage of development, the pragmatic solution is to take the set of values corresponding to the operating parameters chosen by the manufacturer. Where available, the results are those obtained or verified by an independent research institute. In accordance with the international scope of IEA, the technical glazing properties are evaluated according to ISO 9050 and ISO 15099 wherever sufficient information was available to do so.

Manu-facturer	Type	Construction	Develop-ment stage	Maximum area	Source of data in Table 3	Calculation program
Asahi	electrochromic, all-solid-state	unspecified	unspeci-fied	unspeci-fied	Asahi [5]	WINDOW5 [6]
FLABEG	electrochromic, polymer laminate	9 mm EC laminate: 16 mm Ar: low-e on 4 mm float	pilot production	0.9 m x 2 m	ENEA [7], FLABEG [8]	not specified
Gentex	electrochromic, solution-phase	single solution-phase layer between two float panes	laboratory	1 m x 1 m	Gentex [9]	WINDOW5 [6]
Interpane	gasochromic	4 mm float with GC coating: 8 mm Ar: 4 mm float: 16 mm Ar: low-e on 4 mm float	pilot production	1.5 m x 1.8 m	OBU [10], Interpane [11]	WINDOW5 [6]
SAGE	electrochromic, all-solid-state	float with EC and low-e coating: 12 mm air: float	pilot line	N/A	SAGE [12]	not specified
Saint-Gobain	electrochromic, all-solid-state	7 mm EC laminate: 16 mm Ar: low-e on 4 mm float	prototype	N/A	Saint-Gobain [13]	WINDOW5 [6]

Table 2: Summary description of chromogenic glazing investigated in Task 27.

	bleached					coloured				
Manu-facturer	T_{vis}	$R_{vis,\ out}$	SHGC (g value, TSET)	U value $Wm^{-2}K^{-1}$	Inter-mediate states possible	T_{vis}	$R_{vis,\ out}$	SHGC (g value, TSET)	U value $Wm^{-2}K^{-1}$	Standard
Asahi	0.70	0.11			yes	0.20	0.06			ISO9050
FLABEG	0.50		0.36	1.3	yes	0.15		0.12	1.3	DIN 52619
Gentex device 1	0.81	0.09			yes	0.05	0.05			ISO9050
Gentex device 2	0.82	0.09			yes	0.25	0.06			ISO9050
Inter-pane	0.58	0.25	0.49	1.0	not yet	0.13	0.07	0.13	1.0	ISO9050 /ISO150 99
SAGE	0.70		0.51	1.9	yes	0.04		0.09	1.9	NFRC
Saint-Gobain	0.47	0.14	0.28	1.4	yes	0.10	0.08	0.11	1.4	ISO9050 /ISO150 99

Table 3: Technical properties of chromogenic glazing treated in Task 27.

More comprehensive series of measurements have been made on some of the glazing units. The switching rate, as reported in [7] for electrochromic glazing (fig. 1), or the angular dependence of the visible transmittance, solar transmittance and g value (fig. 2), documented in [10] for gasochromic glazing, serve as input for lighting and energy simulations. Other aspects which are important for real applications, such as the spatial homogeneity, have also been reported in [7]. In some cases, both normal-normal and normal-hemispherical transmittance spectral measurements have been made, although not yet published, which characterise the initial state of the glazing before being subjected to accelerated ageing tests.

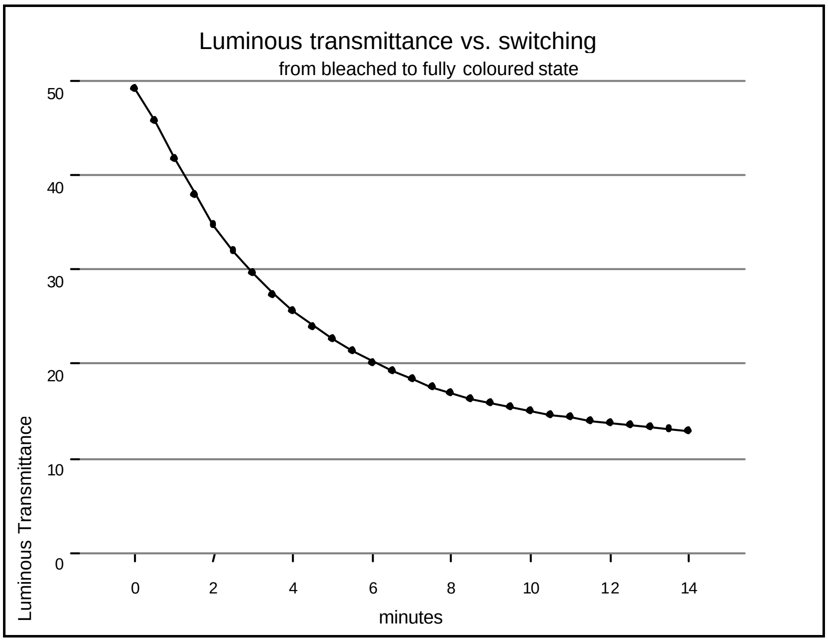

Fig. 1:. Rate of change in the visible transmittance for an electrochromic double glazed unit as specified in Table 2 [7].

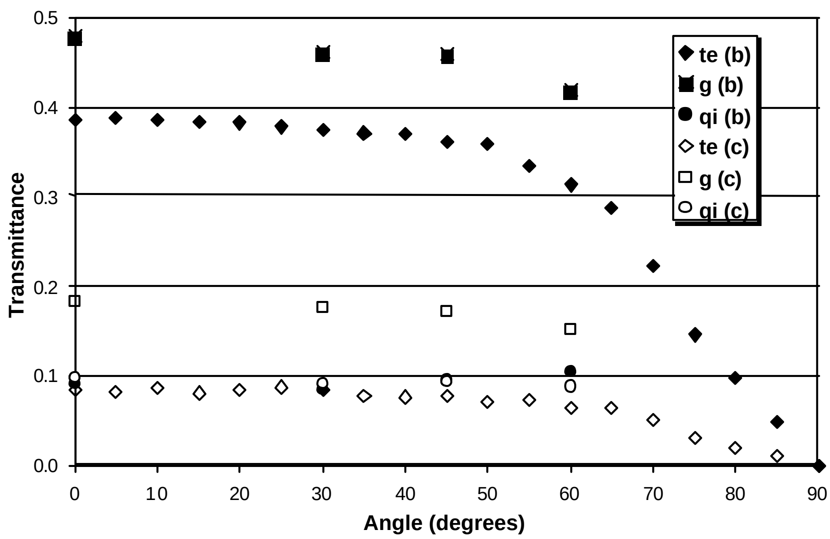

Fig. 2: Angle dependent energy transmittance of a triple glazed gasochromic IGU (t_e solar transmittance; g total solar energy transmittance; q_i secondary heat gain factor; (b) bleached state; (c) coloured state (Source: Fraunhofer ISE report to SWIFT, cited in [10]).

Monitored test rooms

Within the SWIFT programme, performance is also being characterised by the use of test cabins at the University of Athens and Fraunhofer ISE. The glazing is operated under monitored, realistic meteorological conditions, so that the effect of operation according to different switching strategies can be evaluated. Typical strategies include seasonal switching or switching triggered by the internal air temperature or the outdoor solar radiation level. Some experiments are run under special conditions, e.g. by converting the cabin into a giant "hot box" to determine the U value of the installed glazing, which allow the models used in building simulation programs to be validated or modified if necessary to take account of effects that are not included in the standard laboratory characterisation. An example of the comparison between measured and simulated temperatures in such a test cabin with gasochromic glazing is given in fig. 3.

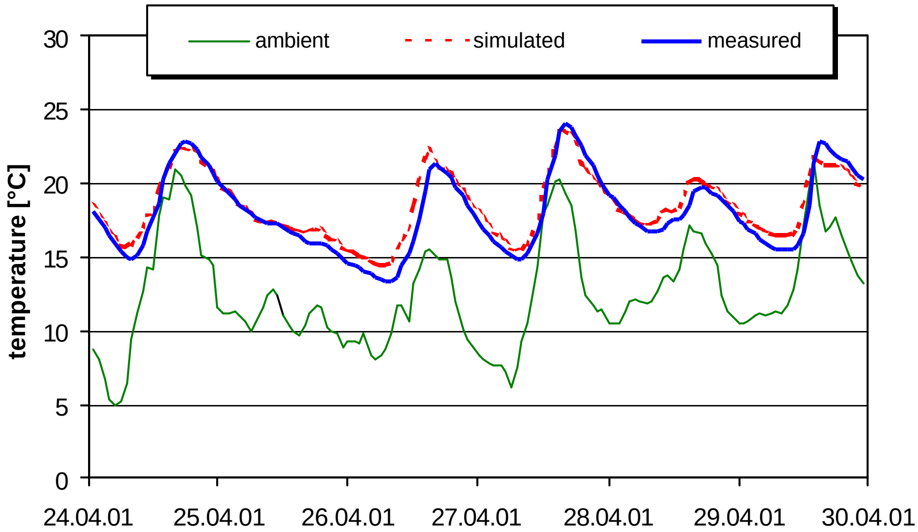

Fig. 3: Comparison of measured and simulated air temperatures in the FASTEST test cabin equipped with gasochromic glazing (Source: Fraunhofer ISE report to SWIFT).

The effect of electrochromic glazing on lighting was studied by LBNL in two side-by-side rooms [4]. Compared to non-switching, solar control glazing with properties identical to the electrochromic glazing in its dark state, the daily lighting energy consumption was reduced by 6 - 24 % during the winter period investigated. It is expected that the reduction would be greater in summer. Some other conclusions of this study were that additional devices such as internal blinds will be needed to prevent glare due to direct sunlight, and that user studies are needed to determine preferences for the transmittance range and switching speeds for different tasks, and to evaluate occupant reactions to the blue-toned light transmitted by the glazing in its coloured state.

In addition, electrochromic windows have been tested in LBNL's Mobile Window Thermal Test Facility (MoWiTT).

Building simulation

Since the first detailed sets of optical and thermal data for chromogenic glazing were provided to Task 27 in 2002, it is expected that results of building energy and lighting simulation will be presented at the Ottawa meeting. The participants will use a range of simulation programs to study the effects of location (Stockholm, Brussels, Rome, Arizona) and control strategy, using the reference office defined in project A1. After simulating the glazing in each of its two extreme states for the whole year, initially a control strategy depending on the indoor operative temperature will be simulated (coloured when the temperature rises above 26 °C, bleached when the temperature falls below 24 °C). In addition to hourly distributions and totals for the energy consumed for heating, cooling and lighting, the outputs should include information on the number of hours per year in each state, the annual number of switching cycles and the external surface temperatures of the glazing.

Parallel to this, work on lighting simulation is proceeding, for instance by the group at TNO, using the criteria developed in the REVIS project to assess visual comfort. Initial results were presented at the combined meeting with Task 27 and Task 31 participants in April 2002 [14].

Ideally, the simulation work will allow both visual-comfort and energy-saving criteria to be applied, so that optimal control strategies can be identified.

User studies

ENEA has conducted the first user study within the framework of Task 27, in which 30 subjects responded to a questionnaire on their reactions to working in a room equipped with electrochromic windows [15]. The test persons were invited to modify both the electrochromic glazing setting and the artificial lighting level in the room according to their personal preference. It was noted that the intermediate transmittance levels were seldom used - the glazing was either completely darkened when it was sunny outdoors, or the glazing was kept bleached if the sky was overcast. In many cases, the subject chose to colour the window and have some artificial lighting as well, in order to obtain a more uniform light distribution in the room. This study also confirmed the need for an additional internal blind to prevent glare due to direct sunlight. Although a northern window was also kept permanently in the clear state, most users were not disturbed by the two differently coloured windows in their field of view. A range of opinions was registered concerning the alternatives of manual or automated control for the glazing, blind and artificial lighting, but the general preference was for individual control.

User studies are being conducted as part of the SWIFT project by TNO, Eindhoven and Fraunhofer ISE, in office rooms equipped with electrochromic and gasochromic glazing.

Durability of chromogenic glazing

A product is generally considered to be durable if its properties remain unchanged over a long period of time. The intrinsic difficulty in characterising the durability of chromogenic glazing is that it is originally intended to be changeable, so that not only the number of properties which are to "remain unchanged" has to be multiplied by the number of states the glazing unit can assume, but also the intended rate of change is an additional important property in itself. If durability tests, in accordance with one main approach, are to be accelerated by increasing the level of an assumed environmental stress, questions immediately arise concerning the most relevant combinations of the sample state (constant at which level, switching between which levels at which frequency) and the environmental stresses applied individually or in combination, maintained at a constant level or cycled.

For the other main approach to durability testing, real-time testing, chromogenic glazing suffers the disadvantage of being a very young product. Even those products which are already on the market have been there for only a few years, and even these are still undergoing further development and optimisation. Naturally, the rate of development is greater still for products at the prototype stage or earlier. As a consequence, the results of real-time testing are only of limited validity.

As stated clearly in a paper summarising an international forum on durability of electrochromic windows, "there are far too many unanswered questions to identify the definitive sets of testing conditions to evaluate the durability of any particular device" [16]. In Project B2, the approach has been adopted of trying to answer some of these open questions by adapting the initial risk analysis from the general durability methodology of Project B1 to the specifics of chromogenic glazing [17].

Initial risk analysis for chromogenic glazing

In accordance with Task 27's focus on applications "for building envelopes" and the manufacturers' stipulations, the object of investigation is the operational chromogenic glazing unit, not its component materials. The general requirements for performance were identified by B2 participants as being:

- high solar gain when heating is required, low solar gain when cooling is required
- "sufficiently" high or low visible transmittance, depending on lighting conditions and requirements
- acceptable switching times - on the order of minutes
- low U value
- acceptable power consumption
- 20 years service lifetime

The main quantities describing the severity of environmental stress expected under operational conditions were characterised as follows:

- outdoor air temperatures between -20 °C and 45 °C
- outer pane temperatures between -20 °C and ~80°C
- solar radiation intensity between 0 and 1100 Wm^{-2}

- solar UV radiation intensity between 0 and 50 Wm^{-2}
- large thermal gradients between shaded and unshaded areas of glazing (electrochromic DGU in frame, gasochromic TGU in frame)
- high relative humidity
- mechanical loads as for conventional glazing (wind, snow, structural, thermal shock/stress)

Whereas information on outdoor air temperatures and the solar radiation intensity on a horizontal surface is generally available from meteorological stations, measured data for the solar UV radiation intensity or glazing surface temperatures is much more limited, so that these quantities have been included in the outdoor measurement programmes at NREL, CSTB and Fraunhofer ISE (see figures 4 and 5). The measured data on glazing temperatures is also supplemented by the surface temperature data that can be output from the building simulation programs otherwise used primarily to characterise energy performance. At the University of Massachusetts, the THERM program is applied to calculate the two-dimensional temperature distribution of chromogenic glazing with partial shading, combining the parameters determined for the performance characterisation and extreme load conditions identified either in measured data sets or building simulations for different locations. The aim is to quantify thermal stress on the glazing.

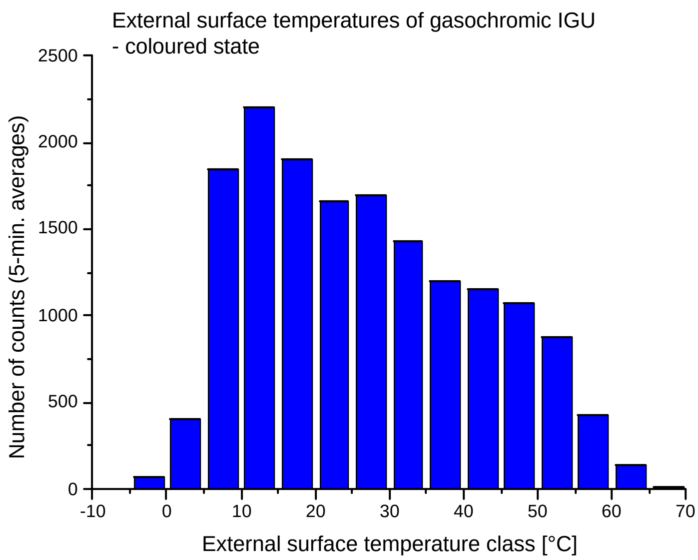

Fig. 4: Distribution of the external glazing surface temperatures for gasochromic triple glazed units in the coloured state, tilted 45° and orientated south for outdoor exposure tests at Freiburg, Germany. 5-minute averages, December 2001 to June 2002. (Source of data: Fraunhofer ISE).

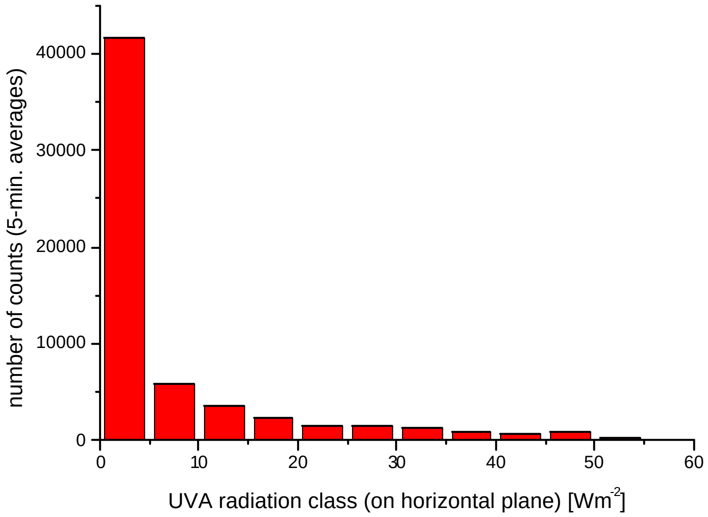

Fig. 5: Frequency distribution of UVA radiation on horizontal plane, measured at Freiburg, Germany. 5-minute averages, December 2001 to June 2002. (Source of data: Fraunhofer ISE).

Based on the general requirements for performance, a list of critical functional properties for chromogenic glazing was prepared, which is to be found in Appendix I. The test methods for evaluating these properties, which are also listed, were fairly obvious; what was less obvious was the effect that a change in these properties would have on the glazing performance in a building. Two different approaches to set performance benchmarks are documented in the appendix. One is again to draw on the building simulation expertise within Task 27 and carry out parameter sensitivity studies, e.g. to characterise the effect of the ratio of maximum to minimum g value (SHGC or TSET) on the total energy demand in the reference office defined in Project A1, and compare the results to good solar control or low-e glazing. In other cases, such as the assessment of appearance or the resistance to mechanical loads, it is considered adequate to apply existing standards for conventional glazing. A list of relevant international and national standards which was collated by B2 participants is given in Appendix II.

The identified possible damage failure modes include the glazing remaining constantly bleached or coloured, switching becoming unacceptably slow, the switching range decreasing, the appearance becoming inhomogeneous (critical in ”steady state”, less critical during switching), the upper and lower transmittance values shifting, delamination, haze, blur, yellowing and colour shifts.

Finally, in designing the initial series of accelerated ageing tests, experience was pooled regarding the most critical factors that can lead to degradation; elevated temperatures (particularly for the glazing in the coloured state), UV radiation, sudden spatial or temporal temperature gradients, air leakage into glazed unit, high humidity, condensation, inappropriate charge injection for electrochromic devices or inappropriate gas supply for gasochromic devices, switching frequency, prolonged periods without switching and mechanical deformation.

Test methods

In the USA, a test method developed by NREL has been accepted as a standard for assessing the durability of absorptive electrochromic coatings on sealed insulating glass units [18]. It involves the exposure of electrochromic windows (ECW) to simulated solar irradiance in a temperature- and humidity-controlled chamber at selected sample temperatures ranging from 70°C to 105°C while the ECW's are cyclically coloured and bleached, with continuous monitoring of the photopic (visible) transmittance at ~22°C and the elevated temperatures (fig. 6). The required performance parameter is that after 50,000 cycles, the photopic transmittance ratio, the ratio of the visible transmittance in the bleached state to that in the coloured state, exceed 4:1 and the visible transmittance in the bleached state exceed 0.50.

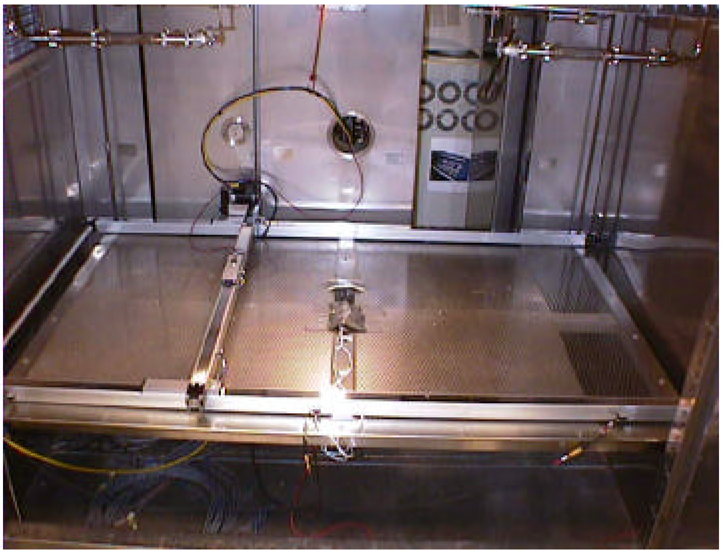

Fig. 6: Sample exposure plane inside the accelerated weathering unit at NREL for accelerated testing of electrochromic windows according to [18] (Source: NREL).

Within the European SWIFT project, a set of five qualification tests has been chosen for initial accelerated testing of complete electrochromic and gasochromic systems at CSTB and Fraunhofer ISE:

1 Cycling at room temperature (1 full cycle period of 40 minutes); total number of cycles 3600
2 Cycling at constant air temperature of 65°C, HR 5-25% and solar radiation (1 sun) with 40-minute cycles as 1st test, total number of cycles 3600
3 Cycling at constant air temperature of 5°C, (maximum period of 2 hours for full cycle), total number of cycles 3600 if possible
4 Thermal cycling from –18°C to 53°C (ramp of 14°C/h) and RH according to prEN 1279-2; chromogenic unit constantly in dark state, cycling performance at room temperature before and after test as indicator. Also characterise a coloured reference sample without load (stored for 77 days without switching at room temperature in the dark) for comparison.

5 External thermal shock test analogous to EN12975-2, section 5.5. (1 hour exposure of the window in the coloured state to solar radiation > 850 Wm^{-2}, Tamb > 25 °C; thereafter 15 minutes spraying with water at a temperature of < 25 °C, flowrate in the range 0.03 - 0.05 kg s^{-1} per square metre of glazing area; test to be performed twice).

The performance of the tested glazing is characterised by normal/hemispherical and normal-normal transmittance spectra (300-2500 nm) in the two limit states (bleached and coloured), from which the visible and solar transmittance, and the colour co-ordinates are obtained, and $d\tau_{550nm}/dt$. The measurements are made at the beginning and end of each test, and four further times during tests 1, 2 and 3. Visual observations are also noted or photographed. The aim of these pictures and measurements is to detect changes in optical appearance, performance (transmittance in coloured and bleached states, and switching rate), spatial homogeneity and light scattering.

In parallel, gasochromic and electrochromic IGU's are being exposed outdoors at Fraunhofer ISE and CSTB in test stands which are tilted 45 ° and orientated due south (fig. 7). The glazing is cycled twice a day during the daylight hours. In addition to standard meteorological data, the glazing surface temperature, the UV radiation, solar radiation and daylight incident on the plane parallel to the glazing are monitored continuously. The visible transmittance is used as the performance parameter, and is monitored with luxmeters and spectrometers located outside and behind the glazing units.

Fig. 7: Outdoor test stand for chromogenic glazing and meteorological measurements at CSTB, Grenoble. (Source: CSTB report to SWIFT).

Although the results obtained are clearly of interest to the manufacturers who provided the samples, the main purpose of these tests is to explore whether the behaviour observed during outdoor, real-time testing is reliably reproduced by the accelerated tests. For the reasons given at the beginning of this section, it is still too early to draw conclusions, but it is also hoped that presentation of the methods here will provoke comments and further suggestions.

Conclusions

Within IEA Task 27, co-operation between companies that are developing and producing chromogenic windows, and research institutes with sophisticated measurement and computer simulation facilities, has the potential to accelerate comprehensive characterisation of the performance and durability of these dynamic windows. Initial results of these combined efforts are indicated in this paper. Further work by the group should pave the way for international harmonisation of standards relevant to these windows, and demonstrate the lighting and energy-saving benefits of chromogenic windows, promoting their acceptance among users around the world.

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Appendix I

Specification of functional properties and requirements for chromogenic glazing

Critical functional property	**Test method for determining functional property**	**Requirement for functional capability or performance (benchmarks) and determination methods**
TSET (g value) for different states	Calorimetric or component method from $\tau(\lambda)$, $\rho(\lambda)$	Postulate: $TSET_{max}$: $TSET_{min}$> 3 Benchmark: 10% saving in building energy demand (heating+cooling+lighting) compared to good solar control or low-e glazing for location and "reference office". Determination method: building energy simulation; illuminance on work plane and/or room temperature as control parameters; parameter sensitivity study to variation in $TSET_{max}$: $TSET_{min}$ coupled with realistic variation of $\tau_{vis,max}:\tau_{vis,min}$
τ_{vis} for different states	Spectrophotometric or luxmeter	From ASTM standard test method E2141-01: photopic transmittance ratio of at least 4:1 Benchmark: 10% saving in building energy demand (heating+cooling+lighting) compared to good solar control or low-e glazing for location and "reference office". Determination method: building energy simulation; illuminance on work plane and/or room temperature as control parameters; parameter sensitivity study to variation in $\tau_{vis,max}:\tau_{vis,min}$ coupled to realistic variation of $TSET_{max}$: $TSET_{min}$ ——— Postulate: $\tau_{vis,min}$< 0.1 Benchmark: increase of 10% duration in "tolerable" (low-glare) VDU working conditions in specified geometric configuration compared to good solar control or low-e glazing for location and "reference office". Determination method: lighting simulation coupled to energy simulation; illuminance on work plane and/or room temperature as control parameters; parameter sensitivity study to variation in $\tau_{vis,min}$ for constant $\tau_{vis,max}:\tau_{vis,min}$ coupled to realistic variation of $TSET_{max}$ Postulate: $\tau_{vis,min}$> 0.05 Benchmark: minimum "tolerable" availability of daylight Determination method: standards for natural lighting of offices

α_{sol} for different states	Spectrophotometric	max. α_{sol} for T_{max} < 75 °C at specified location Determination method: temperature distribution in window under extreme environmental conditions
degree of glare, described by transmission components derived from BTDF (REVIS result)	photogoniometric	Threshold value for transmission components. Benchmark: degradation not faster than for good solar control or low-e glazing for location and "reference office". Determination method: durability study on switchable and conventional glazing
view retention index (REVIS result)	equation using transmission components	Threshold value for transmission components. Benchmark: degradation not faster than for good solar control or low-e glazing for location and "reference office". Determination method: durability study on switchable and conventional glazing
$d\tau_{vis}/dt$ for different states	Spectrophotometric or luxmeter	Postulate: $t(\tau_{vis,max})-t(\tau_{vis,min})$ < 10 minutes. Benchmark: increase of 10% duration in "tolerable" (low-glare) VDU working conditions in specified geometric configuration compared to good solar control or low-e glazing for location and "reference office". Determination method: lighting simulation coupled to energy simulation; illuminance on work plane and/or room temperature as control parameters; parameter sensitivity study to variation in $t(\tau_{vis,max})-t(\tau_{vis,min})$ for constant $\tau_{vis,max}$ and $\tau_{vis,min}$ coupled to realistic values of TSET
colour rendering index	Spectrophotometric or luxmeter	Postulate: delta E* < ? Benchmark: "acceptable" colour Determination method: comparison with "accepted" conventional glazing Postulate: Colour shift: <5 in delta E* (CIE) (with time), <1 in delta E* between windows Benchmark: "Tolerable" colour difference Determination method: study on perception of colour in association with glazing
homogeneous appearance	visual inspection, luxmeter	Tolerances for visible defects as specified in guidelines to assess the visible quality of insulating glass units or laminated safety glass, prepared by national glazing trade associations (e.g. DIN EN ISO 12543-6)

homogeneous switching between panes	visual inspection, photo-documentation	Benchmark: "inhomogeneous" duration < 10 minutes per switching process
control unit adaptability	monitoring window operation	Postulate: correct operation for periods in one state ranging from 1 hour to 1 day, glazing temperatures between -20 °C and 80 °C, accumulated cycles between 1 and 14000 Benchmark: < 10 % duration in "incorrect" state for lighting Determination method: parameter variation in building lighting simulation
control unit reliability	Monitoring window transmittance in operation	Benchmark: 95 % availability
U value	Hot-box, hot-plate or calculations from components	e.g. EN673, EN674, EN675, ISO ... Benchmark: U_{cog} < 1.1 $Wm^{-2}K^{-1}$
thermal comfort	determination of "operative temperature" from air and surface temperatures, and incident radiation	Benchmark: "tolerable" comfort Determination method: comparison with "accepted" conventional glazing, statistical study with twin cells
privacy	determination of view obstruction from outside to inside under determined lighting conditions	Benchmark: view obstruction of light curtains or screens
mechanical properties as for conventional glazing	Testing methods as in standards for conventional glazing	prEN 1279
power consumption	power meter	Benchmark: < 10 % of the building energy saved in comparison to good solar control or low-e glazing for location and "reference office". Determination method: as specified above by building energy simulation

Appendix II

Relevant durability testing standards

(October, 2001)

International

DIN EN ISO 12543-1 Glass in building - Laminated glass and laminated safety glass - Part 1: Definitions and description of component parts (1998-08)
DIN EN ISO 12543-2 Glass in building - Laminated glass and laminated safety glass - Part 2: Laminated safety glass (1998-08)
DIN EN ISO 12543-3 Glass in building - Laminated glass and laminated safety glass - Part 3: Laminated glass (1998-08)
DIN EN ISO 12543-4 Glass in building - Laminated glass and laminated safety glass - Part 4: Test methods for durability (1998-08) Summary: Testing at elevated temperature (100°C), high air humidity (100% at 50 °C), UV-enhanced simulated solar radiation (900 Wm^{-2}), monitoring by visual observation and visible transmittance measurement
DIN EN ISO 12543-5 Glass in building - Laminated glass and laminated safety glass - Part 5: Dimensions and edge finishing (1998-08)
DIN EN ISO 12543-6 Glass in building - Laminated glass and laminated safety glass - Part 6: Appearance (1998-08)

Europe

DIN EN 410; Glass in building – Determination of luminous and solar characteristics (1998-12)

DIN EN 673; Glass in building – Determination of thermal transmittance (U value) – calculation method (including Amendment A1:2000) (2001-01)

DIN EN 1096; Glass in building - Coated glass
DIN EN 1096-1 Part 1: Definitions and classification (Section 6; Visual faults) (1999-01)
DIN EN 1096-2 Part 2: Requirements and test methods for durability of A, B and S coatings (2001-05)
DIN EN 1096-3 Part 3: Requirements and test methods for durability of class C and D coatings (2001-05)
are applied to test the durability of thin films. They include the following tests:
Condensation resistance
Acid resistance
Neutral salt spray resistance
Solar radiation resistance

prEN1279 – Glass in Building; Insulating Glass Units
(It is anticipated that this standard will come into force by the end of 2001.)
Summary of aspects which may be relevant for accelerated testing of chromogenic glazing
prEN1279-1; Generalities, dimensional tolerances and rules for the system description (1995-09)

- The following characteristics are treated:
- resistance to fire
- reaction to fire
- external fire performance
- bullet resistance: shatter properties and resistance to attack
- explosion resistance: shatter properties and resistance to impact
- burglar resistance: shatter properties and resistance to attack
- pendulum body impact resistance: shatter properties (safe breakability) and resistance to impact
- mechanical resistance: resistance against sudden temperature changes and temperature differentials (prEN 1863-1, prEN 12150-1, prEN 12337-1, prEN WI00129055-1)
- mechanical resistance: resistance against wind, snow, permanent load and/or imposed loads of the glass unit (prEN 13474)
- mechanical resistance: resistance against wind, snow, permanent load and/or imposed loads of the edge seal where required (e.g. for structural sealant glazing) (prEN 13022)
- direct airborne sound reduction
- energy conservation and heat retention; thermal transmittance (U value) (EN 673)
- energy conservation and heat retention; light transmittance and reflection (EN 410)

- energy conservation and heat retention; total solar energy transmittance (solar factor) (EN 410)
- optical and visual quality for bubbles, optical distortions, bows, etc (prEN 1096, prEN 12150, WI00129055, WI00129..., prEN 1863, EN 12543-6)

prEN1279-2; Long-term test method and requirements for moisture penetration (1994-08)

- Section 5 describes a climate test which must be passed by any gas-filled, insulating glass unit. It is designed as an accelerated test for moisture penetration into a sealed glass unit.
- The high humidity/temperature test procedure consists of two parts.
- The first part consists of 56 temperature cycles, each lasting 12 hours. After an initial temperature decrease at 14 °C/h from room temperature to –18 °C, one complete cycle is defined as follows: 1 h at –18 ±1°C, 5 h temperature increase of (14±2)°C/h, 1 h at 53±1°C, 5 h temperature decrease of –(14±2)°C/h (to -18±1 °C). While the temperature is lower than +10 °C, the relative humidity is not specified, but a value less than 20 % is implied. At +10 °C, the relative humidity should be 20 %, and then increase with the temperature until a value exceeding 95 % is held while the temperature exceeds 42 °C (a total of 4 hours). The relative humidity should then decrease with the temperature until the value of 20 % is again reached when the temperature is +10 °C.
- The second part consists of maintaining the samples at a constant temperature of 58 °C and relative humidity exceeding 95 % for seven weeks.
- The dew point and moisture content of the sealed glass unit are measured before and after the climate test, and the average moisture penetration index is determined.
- This test does not include exposure to UV or solar simulator radiation.

prEN1279-3; Long-term test method and requirements for gas leakage rate and for gas concentration (1995-08)

tolerances

- The climate test employed here is as specified in prEN1279-2, with the following modifications: the number of cycles is reduced to 28, and the time at a constant temperature of 58°C is reduced to 4 weeks.
- The gas leakage rate at 20 °C is determined after subjecting the test specimen to the climate test.

prEN1279-4; Methods of test for the physical attributes of edge seals (1996-10)

- Section 5.1.3 describes ageing regimes which must be applied to any gas-filled, insulating glass unit. They are intended as accelerated ageing tests for the adhesion and cohesion of edge seals (glass-sealant-glass joints).
- The test specimens are glass-sealant-glass joints (without a gas-filled cavity).
- The test consists of three parts; heat exposure, water immersion and UV exposure. Different test specimens are used for each test, i.e. the tests are not cumulative.
- The test specimens are heat aged in a closed oven at 60±2 °C for 168±5 h.
- The test specimens are immersed in distilled or de-ionised water for 168±5 h.
- The test specimens are exposed for 96±4 h to UV irradiation perpendicular to the glass at an intensity in the UVA range (315 nm-380 nm) of 40±5 Wm^{-2}.
- The tensile strength is measured for unexposed specimens and for specimens exposed to each type of ageing condition.

prEN1279-5; Evaluation of conformity (2001-10)

- From Table 1: Characteristics of interest for factory production control:
- periodic, low-frequency tests and inspections:
  - visual inspection of the seal geometry
  - short climate test (21 days at T=58 °C, r.h. ≥ 95 %)
  - check of gas concentration
  - gas permeability test
  - fogging test results

prEN1279-6; Factory production control and periodic tests (1997-04)

- From Annex C: Fogging test
- This test checks whether unacceptable condensation appears on the glass surfaces facing the unit cavity, due to release of volatile substances. The release of gaseous substances is achieved by applying heat at a point on the relevant organic component. Condensation is achieved by cooling a spot of the glass surface.

- The heated surface temperature nearest to 20 – 30 % of the relevant component is to be held between 50 and 60 °C.
- The cold spot, which is to have an area of 10 % of the unit surface, is to be 27 – 33 K lower than the heated surface temperature, as specified above.
- The test duration is 168±4 h.
- The test specimens are examined for fogging or permanent condensation visually in a specified viewing box.

DIN EN 1863-1; Glass in building; Heat strengthened soda lime silicate glass – Part 1: Definition and description (2000-03)
DIN prEN 1863-2; Glass in building - Heat strengthened soda lime silicate glass - Part 2: Evaluation of conformity (2001-09)

DIN EN 12150-1; Glass in building – Thermally toughened soda lime silicate safety glass - Part 1: Definition and description (2000-11)
DIN prEN 12150-2; Glass in building - Thermally toughened soda lime silicate safety glass - Part 2: Evaluation of conformity (2001-09)

DIN EN 12337-1; Glass in building – Chemically strengthened soda lime safety glass - Part 1: Definition and description (2000-11)
DIN prEN 12337-2; Glass in building – Chemically strengthened soda lime safety glass - Part 2: Evaluation of conformity (2001-09)

pPrEN 12975-2 Thermal solar systems – Collectors – Part 2: Test methods (1998-01)

DIN EN 12898 Glass in building – Determination of the emissivity (2001-04)

DIN prEN 13022; Glass in building – Structural sealant glazing – Part 3: Sealants, test methods (1998-01)

prEN 13474; Glass in building – Design of glass panes – Part 2: Design for uniformly distributed loads (2000-05)

prEN WI00129055-1; Glass in building – Heat soaked thermally toughened soda lime silicate safety glass

National:
France
MO3 Humidity test for coated IGU (In-house test developed and conducted by CEBTP or OMV)
MO 08 Adherence test for coated IGU (In-house test developed and conducted by CEBTP or OMV)
MO20 Compatibility of sealants with glass coating (In-house test developed and conducted by CEBTP or OMV)

(Source of MO standards
CEBTP
M.Moïse Riotteau (Dep. Fenêtres et Fassades)
Domaine de Saint-Paul
B.P. 37
78470 Saint-Rémy-Lès-Chevreuse
France
Tel. 01.30.85.23.32, Fax 01.30.85.23.20)

Germany
DIN 1286-1 Insulating glass units; air filled; aging behaviour (1994-03)
DIN 1286-2 Multiple-walled insulating glazing units; gas filled; aging behaviour, limiting deviations of gas volume fraction (1989-05)
DIN 52 293 Testing of glass; testing the gas tightness of gas-filled insulating glass units (1987-12)
DIN V 52 293 Part 2 Testing of glass; testing the gas tightness of gas-filled multiple-walled insulating glazing units; determination of the loss in gas by gas chromatography and thermal conductivity detector (1988-11)
DIN 52 294 Testing of glass; determination of the loading of desiccants in multiple –walled insulating glazing units (1988-11)

DIN 52 344 Testing of glass; testing the effect of alternating atmosphere on multilayer insulating glass (1984-05)
DIN 52 345 Testing of glass; determination of dew point temperature of insulating glass units; laboratory test (1987-12)

Japan
In Japan, JIS (Japanese Industrial Standard) is the only national standard related to this issue, which is listed below. However, this is the only necessary minimum and mostly specifications are determined between manufacturers and customers.

List of JIS related to glazing and its testing procedures
A-5759:Adhesive Films for Glazings
B-4111:Solar Water Heater for Dwellings
B-7751:Glass-Enclosed Carbon-Arc Type Apparatus for Artificial Light Exposure Tests
B-7752:Light-and-Water-Exposure Apparatus (Enclosed Carbon-Arc Type)
B-7753:Light-and-Water-Exposure Apparatus (Open-Flame Sunshine Carbon-Arc Type)
B-7754:Light-Exposure and Light-and-Water-Exposure Apparatus (Xenon-Arc Lamp Test)
R-3106:Testing Method on Transmittance and Reflectance for Daylight and Solar Radiation and Solar Heat Gain Coefficient of Flat Glass
R3211:Safety Glass for Road Vehicles
R3212:Test Method of Safety Glass for Road Vehicles

USA
ASTM E 2141 - 01 Standard Test Methods for Assessing the Durability of Absorptive Electrochromic Coatings on Sealed Insulating Glass Units (2001-08)
Summary: Exposure of electrochromic windows (ECW) to simulated solar irradiance in a temperature- and humidity-controlled chamber at selected sample temperatures ranging from 70°C to 105°C while the ECW's are cyclically coloured and bleached, monitoring of the photopic (visible) transmittance at ~22°C and the elevated temperatures.

1. Fenestration Component Test Methods and Specifications
   - 1.1 Perimeter Sealants
     - 1.1.1 AAMA 808.3 "Specifications for Exterior Perimeter Sealing Compounds
     - 1.1.2 ASTM C 920 "Specification for Elastomeric Joint Sealants"
     - 1.1.3 ASTM C1085 "Standard Specification for Butyl-Based Solvent-Release Sealants"
     - 1.1.4 AAMA 803.3 "Specification for Narrow Joint Seam Sealers"
     - 1.1.5 ASTM C1311 "Standard Specification for Solvent-Release Sealants"
     - 1.1.6 ASTM C834 "Standard Specification for latex Sealants"
   - 1.2 Glazing Compounds
     - 1.2.1 ASTM C669 "Standard Specification for Glazing Compounds for Back Bedding and Face Glazing of Metal Sash"
     - 1.2.2 ASTM C797 "Standard Practices and Terminology for Use of Oil and Resin Based Putty and Glazing Compounds"
     - 1.2.3 ASTM C741 "Standard Test Method for Accelerated Aging of Wood Sash Face Glazing Compound"
     - 1.2.4 AAMA 802.3 "Specification for Ductile Back Bedding Compound"
     - 1.2.5 AAMA 805.2 "Specification for Bonding Type Bedding Compound"
     - 1.2.6 AAMA 804.3; 806.3; 807.3 "Specifications for Back Bedding Mastic Type Glazing Tapes"
     - 1.2.7 ASTM C1281 "Standard Specification for Performed Tape Sealants for Glazing Applications"
     - 1.2.8 AAMA 810.1 "Specification for Expanded Cellular Glazing Tapes"
   - 1.3 Gaskets
     - 1.3.1 ASTM C509 "Standard Specification for Cellular Elastomeric Preformed Gasket and Sealing Material"
     - 1.3.2 ASTM C864 "Specification for Dense Elastomeric Compression Seal Gaskets, Setting Blocks and Spacers"
   - 1.4 Spacers
     - 1.4.1 SIGMA A-200 "Voluntary Test Methods and Voluntary Performance Quality Assurance Criteria for Spacers for Sealed Insulating Glass Units"
   - 1.5 Insulating Glass Units
     - 1.5.1 ASTM E-774 "Standard Specification for Sealed Insulating Glass Units"

1.6 Glass

1.6.1 ASTM C1036 "Standard Specification for Flat Glass"

1.6.2 ASTM C1048 "Standard Specification for Heat-Treated Glass"

1.6.3 ASTM C1172 "Standard Specification for Laminated Architectural Flat Glass"

1.6.4 ASTM E1300 "Determining Load Resistance of Glass in Buildings"

1.7 Desiccant

1.7.1 SIGMA A2801 "Recommended Voluntary In-Plant Test Methods and Performance Criteria for Desiccants for Sealed Insulating Glass Units"

2. Fenestration Assembly Tests

2.1 A number of fenestration tests currently exist for determining performance criteria. These tests include Water Penetration (ASTM E-547 or ASTM E-331); Thermal Transmission (ASTM C1199 or AAMA 1503.1); Structural Strength (ASTM E-330); and Chromogenic Functionality (ASTM-TBD). Chromogenic functionality will include but not be limited to maximum controllability in the colored and bleached states, their visual appearance, switching time, and photopic contrast ratio between the colored and bleached states.

2.2 To meet the requirement of this practice, a product shall be tested to meet the requirements of a nationally recognized product performance standard (see AAMA/NWWDA 101/IS2-97) in the following sequence.

2.2.1 The specimen shall be tested in accordance with ASTM E283.

2.2.2 The specimen shall be tested in accordance with ASTM E547 (or E331).

2.2.3 If specified, the specimen shall be tested in accordance with ASTM C1199 (or AAMA 1503).

2.2.4 The specimen shall be tested in accordance to ASTM E330 (at designated pressures for design classification).

2.2.5 The test specimens shall be chosen in accord with Section 8.

2.2.6 The test specimen must pass a qualification test, which simulates a sudden rainstorm (water-spray) when the device is operating, by maintaining its chromogenic functionality.

2.3 The specimen shall then be exposed to the following accelerated tests (in sequence).

2.3.1 The specimen shall be exposed to 1/2 of the specified cycles as referenced in AAMA 910-93 "Voluntary Life Cycle Specifications and Test Methods for Architectural Grade Windows and Sliding Glass Doors."

2.3.2 The specimen shall be tested for 100 cycles at 0.75 (75%) of the designated pressure for the design classification in accordance with ASTM E-1233 "Standard Test Method for Structural Performance of Exterior Windows, Curtain walls, and Doors by Cyclic Static Air Pressure."

2.3.3 The specimen shall be exposed to the remaining half of the specified motion cycles as reference in AAMA 910-93 "Voluntary Life Cycle Specifications and Test Methods for Architectural Grade Windows and Sliding Glass Doors"

2.4 Upon completion of the accelerated tests, the specimen shall be tested in accordance with Section 2.2.1, 2.2.2, and 2.2.3.

2.4.1 The results of these tests shall be reported in Section 9.

Useful websites

www.afnor.fr Association française de normalisation
(Information provided in French and English on NF and EN standards)

www.din.de Deutsche Industrie Norm
(Information provided in German and English on DIN and EN standards)

www.jisc.org Japanese Industrial Standards Committee
(Information provided in Japanese and English on JIS standards)

global.ihs.com Global Engineering Documents
(Information in English on international and national standards)

www.iso.ch International Organization for Standardization