Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

ELECTROCHROMIC WINDOW SYSTEM EVALUATION AT HEIMDAL SECONDARY SCHOOL

ZEN MEMO No. 28 – 2020

Ruth Woods, Judith Thomsen, Steinar Grynning, Nicola Lolli | SINTEF

Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

ZEN MEMO No. 28

Ruth Woods, Judith Thomsen, Steinar Grynning and Nicola Lolli (SINTEF)

Heimdal secondary school: electrochromatic window system evaluation

Norwegian University of Science and Technology (NTNU) | www.ntnu.no
SINTEF Community | www.sintef.no

https://fmezen.no

Preface

Acknowledgements

This memo has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). The authors gratefully acknowledge the support from the Research Council of Norway, the Norwegian University of Science and Technology (NTNU), SINTEF, the municipalities of Oslo, Bergen, Trondheim, Bodø, Bærum, Elverum and Steinkjer, Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, Asplan Viak, Multiconsult, Sweco, Civitas, FutureBuilt, Hunton, Moelven, Norcem, Skanska, GK, Nord-Trøndelag Elektrisitetsverk - Energi, Smart Grid Services Cluster, Statkraft Varme, Energy Norway, Norsk Fjernvarme and AFRY.

The Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities

The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no greenhouse gas emissions and thereby contributes to a low carbon society.

Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre in order to plan, develop and run neighbourhoods with zero greenhouse gas emissions. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m^2 and more than 30 000 inhabitants in total.

In order to achieve its high ambitions, the Centre will, together with its partners:

- Develop neighbourhood design and planning instruments while integrating science-based knowledge on greenhouse gas emissions;
- Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for a broader public use; This includes studies of political instruments and market design;
- Create cost effective and resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies;
- Develop technologies and solutions for the design and operation of energy flexible neighbourhoods;
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system;
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, Campus Mære in Steinkjer, Ydalir in Elverum, Campus Evenstad, NyBy Bodø, and Zero Village Bergen.

The ZEN Research Centre will last eight years (2017-2024), and the budget is approximately NOK 380 million, funded by the Research Council of Norway, the research partners NTNU and SINTEF, and the user partners from the private and public sector. The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF.

https://fmezen.no
@ZENcentre
FME ZEN (page)

English summary

The memo presents the results from user evaluation and daylight measurements of electrochromic glass (EG) installed in Heimdal secondary school (Heimdal vgs.) in Trondheim, Norway. EG is a solar shading technology that is integrated in the insulated glazing unit of a window. It is a system with no moveable parts. By imposing an electrical current to the EG, the solar heat gain coefficient and visible light transmittance can be controlled making it function in a similar way to an external solar shading unit. The technical properties and technical data of electrochromic technologies are well documented, but there is little documented operational experience. Heimdal vgs. chose to be a Nordic pilot for the use of EG in parts of the building's façade. Skanska organised the evaluation of the EG in collaboration with Trøndelag County Council and the Research Centre for Zero Emission Neighbourhoods in Smart Cities (WP3 ZEN).

Solar shading is necessary for educational purposes, and the technology is promising. With a system integrated in the glazing unit, no externally mounted shading is in theory needed. EG can provide users with a view to the exterior when activated. This is blocked when a traditional screen is used. EG have no moveable parts and this can lead to less maintenance. However, major technical issues and malfunctions were experienced at Heimdal vgs., and the system received negative feedback from the building users. Based on the users' perception at Heimdal vgs. we do not recommend EG as the only shading system in rooms intended for educational purposes.

Much of the technology found today in classrooms requires individually controllable lighting – computers and smart boards do not work well when used in combination with direct sunlight. Powerpoint presentations require darkened classrooms and the possibility to quickly change from a dark to a light room. Similar issues apply in individual offices, shared office spaces, or group rooms. In rooms with EG, sunlight on screens (glare) and overheating were experienced due both to the slow response of the system to sun on the windows and to repeated system failure. A solar shading system that is unable to respond immediately to the needs of the building users limits the building`s functionality. Even when functioning as intended, EG is unable to remove all the glare and does not have the necessary short response-time when switching from light to dark. The technical quality and the systems for control and operation of the EG were poor. The building is still in the adjustment phase, and it is common that operation procedures are tested and adjusted during the first year. During this adjustment phase, proper training and instructions for maintenance personnel and other building users should be given for the system. There is much to be learnt from the challenges experienced at Heimdal vgs.

Contents

1. Introduction

The memo presents the results from user evaluation and daylight measurements of electrochromic glass (EG) installed in Heimdal secondary school (Heimdal vgs.). The evaluation took place within the first year of operation. It is common procedure that operation of technical installation is tested and adjusted during the first year. In addition to the evaluation, the memo includes some reflections about the methodology used, the challenges arising due to installation of the EG and makes some suggestions about the future use of the EG system.

Solar shading is always included in climate-responsive facades for new buildings, due to technical regulations. It helps to reduce a building's energy requirements and contributes to a good indoor climate. Electrochromic glass is a solar shading technology that is integrated in the insulated glazing unit (IGU) of a window (Tällberg et al 2019). It is a system with no moveable parts. By imposing an electrical current to the EG, the solar heat gain coefficient and visible light transmittance can be controlled making it function in a similar way to an external solar shading unit. Mechanical external solar shading and electrochromic windows are similar in the sense that, shading is controlled automatically or manually. In both cases this can be done based on for example registered solar radiation or the temperature outdoors or in a room or zone. However, the effect on shading and thermal conditions in a room differs. In Heimdal vgs. both types of solar shading have been installed in different areas of the school. Electrochromic technology is not yet widely used in Nordic climates. The technical properties and technical data of electrochromic technologies are well documented (Dussault & Gosselin, 2017), but there have been few investigations and there is little documented operational experience from actual use of electrochromic windows. Heimdal Secondary School chose to be a Nordic pilot for the use of EG in parts of the façade. The case actions at Heimdal vgs. were intended to evaluate user response to EG, to the rooms where the system is installed, and to measure daylight conditions in these rooms.

Skanska organised the evaluation of the EG in collaboration with Trøndelag County Council and the Research Centre for Zero Emission Neighbourhoods in Smart Cities (WP3 ZEN).

1.1 The School

Heimdal vgs. which opened in August 2018, is one of the largest secondary schools in Norway, with six education programs specialising in arts, sports, music, dance, drama, electrician studies, services and transport (ICT services), and health. In addition to classrooms with space for 1020 pupils, the building houses a large multipurpose sports hall and a cultural arena. The multipurpose hall is known as the "Kolstad Arena» and is Kolstad Handball's home ground. The culture arena (concerts and cultural events) has seating for 350 people.

Gross area: 30,000 m2. Heimdal vgs. and multipurpose sports hall. Location: Blisterhaugveien 15, 7078 Saupstad, Trondheim Municipality

Trøndelag County Council, who owns and runs all the high schools in Trøndelag county, owns and runs the school. The school is a zero emission building and was one of nine pilot buildings associated with the Centre for Zero Emission buildings (ZEB). The school has EG installed on the 2nd floor, in most windows on the West, South and East façades (figure 1). A few EG windows are also installed on the 1st and 3rd floor, however, the major part of the windows on the 1st and 3rd floor have external solar shading installed. The rooms with electrochromic solar shading have a variety of uses: offices (individual and group), classrooms, and group workspaces for pupils.

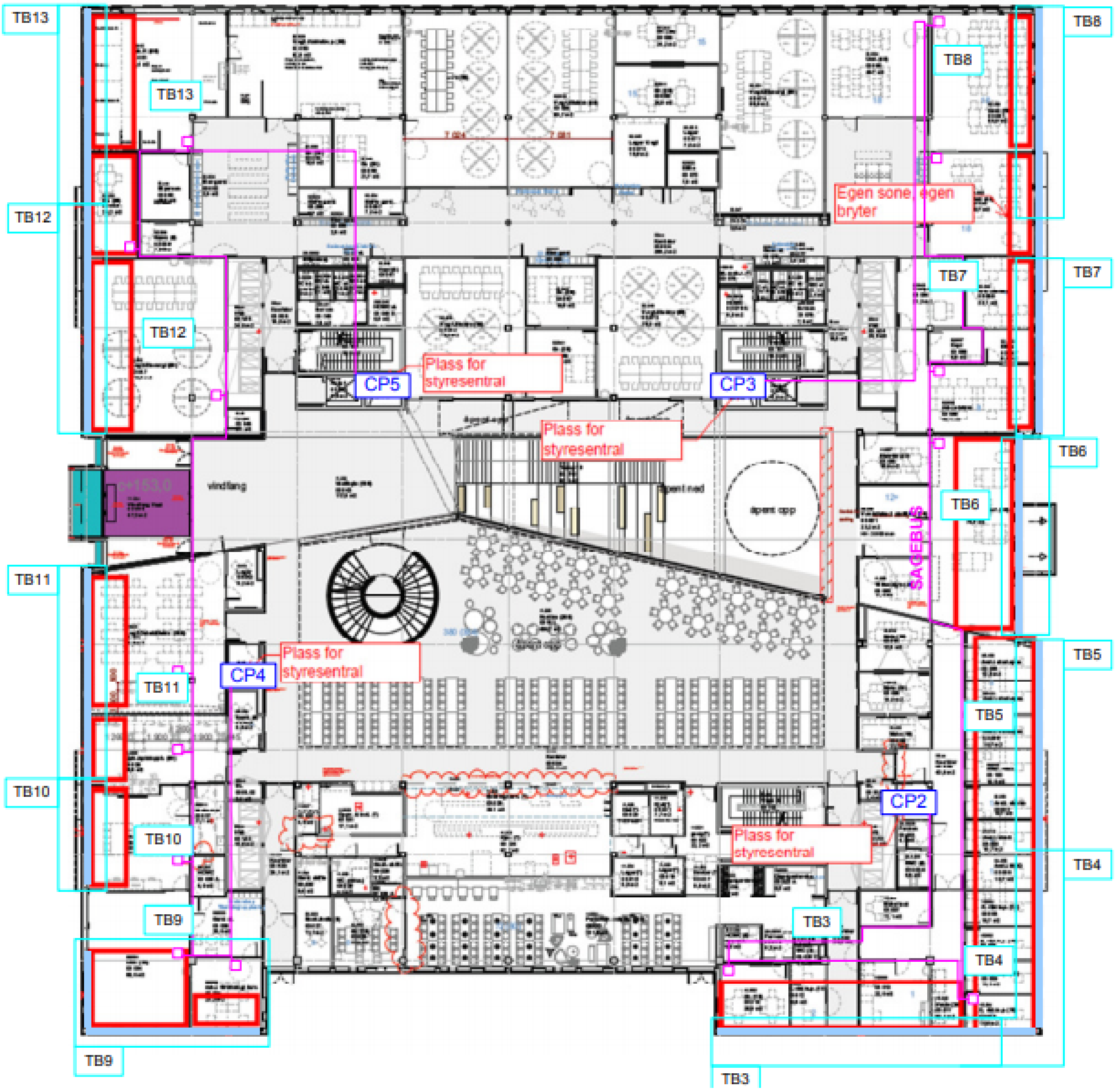

Figure 1: The red boxes indicate the location of the electrochromic windows on the 2nd floor of Heimdal school.

2. Methodology

The evaluation of the EG system has two methodological parts,

- User evaluation, where qualitative methods, primarily semi-structured group and individual interviews, were applied.
- Daylight analysis: measurements of daylight factor (DF) with and without the activation of the solar shading system (screen, EC).

A number of questions were proposed by the project team. The response to the questions is summarized in the results section of the report.

• Degree of screening regarding solar heat (directly on to the body) and blending. If there is an internal blending device, is it used as well and when? Does the electrochromic glass react fast enough when there are variations in the cloud cover / sun?
• How does the control of the glass together with lighting control work? Are users satisfied with the lighting conditions (good regulation)?
• How do the users perceive the changes to the darkness of the glass? Do they notice it and is it disturbing/distracting?
• How do users perceive visibility when the glass becomes darker?
• How do the users like the design? Is it "cool" or not as nice?
• Operator's user experience - are there more or less challenges compared with traditional exterior solar shading systems?

2.1 User Evaluation

A user evaluation process is intended to establish the usability of a system, for example, does the user consider that it is easy and efficient to get things done when using the system? And how does a system affect the experience of comfort? At Heimdal vgs. the experience with the EG was evaluated from a performance perspective and with focus on the user’s subjective response. User evaluation rarely takes place early in a development process. It looks into lived experiences, assessing whether the final product is on the right track, taking place after a period of use (Vermeeren et al. 2010). The length of the use period can vary. Other qualities included in user evaluation are perception of aesthetic quality, and identification and value, i.e. do the users identify themselves with the product or consider it to be valuable to them. There exists an important contradiction in a user evaluation process, because although it is a response to the design and is about avoiding expensive failures, it takes place after the system has been installed. Therefore, if there are serious problems with a system, it is often costly and difficult to do anything about the problems uncovered. User evaluation can, however, have relevance. Feedback about the system gathered through user evaluation has implications for the management of the system, its use in other locations or with other user groups, and in a worst-case scenario it can potentially support replacement of the system. In a best-case scenario, a user evaluation can supply the principal with success stories (Janda and Topuzi 2015) that encourage the use and marketing of a new system.

Several qualitative methods were discussed for the user evaluation process at Heimdal vgs., participant observation, questionnaires, and interviews. Due to the limited number of respondents that were willing to participate, semi-structured interviews were the main method chosen. An interview is often understood as a social event, where two people, often relative strangers, sit down and talk about a specific topic (Pink 2015). In semi-structured interviews the questions are also prepared, but a more open conversational style allows follow-up questions to be included (Skinner 2012). At Heimdal vgs. each interview took approximately one hour in a classroom or room where EG was installed. One of the interviews was extended as the interviewee expressed an interest in guiding us around the building.

The original intention was to gather response from at least three different user groups, technical management, administrative and teaching staff, and pupils. Three different channels were used to gain contact with informants: via the technical staff, through the Trøndelag County representatives in the project team, and directly to the school through email and telephone. Due to lack of interviewees, we had to focus on teaching staff and technical management. The evaluation process was anchored within the project team which included representatives from Skanska, Trøndelag County, SINTEF, and NTNU. The team had good contact with the technical management who are responsible for the everyday running of the EG system at Heimdal vgs. but struggled to establish a line of communication with the administration and teaching staff at the school. We therefore interviewed fewer members of staff than originally intended. Contact with pupils also depended on contact with teaching and administration staff. In the end we conducted two semi-structured group interviews, one with the three representatives from technical management and one with two representatives from the teaching staff. One individual interview with a member of the teaching and administration staff was also conducted. In addition, we talked to staff that we met during our site visits.

Interviewees signed a consent form, agreeing to participate in the research project. Presentation of the results preserves the anonymity of the individuals involved.

Summary of the main actions during user evaluation

1. Meeting with project team and a representative from technical management.
2. Interview guide developed based on suggestions by Skanska and initial meetings.
3. Discussion with 3 members of technical management team and 2 teachers (group interviews)
4. Individual semi-structured interviews with a member of the teaching staff who used rooms where EG was installed.

2.2 Daylight measurements

Daylight measurements were carried out by measuring the daylight factor (DF) in some of the rooms (two classrooms and two offices). According to the Norwegian Building Code TEK-17 the daylight factor should be larger than 2 % in rooms such as the ones investigated here. Four rooms were chosen for the daylight measurement: two on the 3rd floor and two on the 4th floor. The rooms were chosen to represent classrooms and offices, and the two floors were chosen for comparative reasons, because the 3rd floor rooms are equipped with EG windows, while on the 4th floor the shading system is a mechanized textile curtain integrated in the external frame (a zip-screen). The rooms are described in Table 1 with codes and their respective characteristics of use and the shading system.

Floor	Room Code	Use	Shading system
3rd	P3R1	Classroom	EG
3rd	P3R2	Office	EG
4th	P4R1	Classroom	Textile
4th	P4R2	Office	Textile

Table 1 Room codes and characteristics

The rooms chosen were similar in size, use, and have the same eastern orientation. The daylight factor (DF) is evaluated as the ratio of the illuminance level on a horizontal plane inside the building to the illuminance level of an unobstructed location outside [1]. Two identical Konica-Minolta Illuminance Meters T-10A were used. The first instrument was mounted on the building roof, equipped with its own data acquisition system. The illuminance level was acquired for the whole duration of the measurement period. The second instrument was used for the indoor measurements. According to the governing standard for measuring the DF was measured at a height of 80 cm from the floor. This corresponds to the typical height of a working desk. In each room the floor was discretised with a grid of 100 cm by 100 cm, at a distance 50 cm from the room walls. The illuminance meter was placed at the intersection of each grid line (i.e. the measurement points), the surrounding area was cleared of any possible non-fixed barriers and the data acquired for a sample time of 30 seconds with a measurement frequency of 1 second in each point. In the last two rows of grid lines at the back of the room (opposite the window side), the measurements were taken at every two grid intersections with a chessboard distribution. This was done because the illuminance level at the back of the rooms was lower and less influenced by the outdoor illuminance.

The procedure was repeated twice for each room, the first time with the solar shading/EG deactivated, the second time with the solar shading/EG activated. In the data post processing, the illuminance values taken for each measurement point were averaged and compared to the outdoor illuminance averaged over the corresponding measurement time. The ratio between these two averages was used to calculate the daylight factor for the rooms. In the following sections the results are given per measurement point and as a total average for the whole room.

2.3 Limitations of the Daylight Factor measurements

The Daylight Factor (DF) should be measured under uniform overcast sky conditions (Byggforskserien, 421.626). This ensures that the sky luminance is uniform, and the illuminance measured in the building is not affected by room orientation. The illuminance measurements shown in this report were taken under a clear sky, with the sun shining south. The outdoor luxmeter was hit by direct sunlight and gave an average illuminance of circa 79000 lux during the whole measurement period. On the other hand, the rooms where the measurements were taken faced east and received no direct sunlight during the measurement period. This led to two different illuminance conditions as the rooms where illuminated by a lower sky luminance than that measured by the outdoor device. From this perspective, the measurements in this report gave a lower DF than what would be expected under a uniform overcast sky condition. Hence, the measured values should not be looked on as documentation of the daylight conditions of the rooms under standardized conditions, nor in relation to the TEK-17 national building codes. However, given that the rooms all have the same orientation, the comparison between the DF calculated with and without the shading devices remains valid, as the outdoor illuminance during the measurement process had little variation.

3. Results from interviews

All the interviewees stated that they were in general “really pleased with the school building.” However, new buildings usually need time to tune in their systems, and the technical management has been busy making adjustments during Heimdal vgs. first year of use. The operation of the EG has been unusually challenging from the perspective of both the technical and teaching staff. The functionality and the daylight conditions associated with the EG were not as expected.

The following text points out the critical issues experienced during the first year with the EG system. Unfortunately, there is little feedback from the users interviewed that supports the use of EG in buildings which have educational purpose.

3.1 Challenges

A main challenge described by the interviewees is that the EG shading system is very slow in responding to changing light conditions outside. According to building users (technical and teaching staff) windows need approximately 20 minutes to change the colour from transparent to maximum shading. This was not measured during the on-site inspection but corresponds to the specifications of the EG-manufacturer. This is challenging when the sun is shining into an office or a classroom, and if, as often is the case, the users experience an immediate need for shading. Another challenge reported was that the classrooms where EG is installed without additional blind, do not get dark enough to show powerpoint presentations. An associated issue is that when there is no direct sunlight on the EG, rooms do not get dark at all, because they do not require solar shading. However, powerpoint presentations generally require a darkened room. This issue can be overridden manually, but not all rooms with EG at Heimdal have a switch to operate the EG. In the individual offices, which are quite small spaces, the room can get too dark,

> “On the outside it looks like a large black wall, with only limited view into the building. But it becomes dark in this room. It can get a bit gloomy. We have quite small offices and it can be a bit much with a massive black wall (the window with EG covers one wall in the office).”

In summary for the classrooms, we found that:

- If the sun is not hitting the window directly, the system works very slowly.
- Some rooms have a control button, some rooms do not. Individual control is thus limited.
- It is not possible to darken the classroom enough without extra shading (which does not exist in the classrooms).

A different challenge found in small offices was that

- It gets very dark in the offices when there is a lot of sun outside.
- The small offices easily get overheated because the EG does not protect the glass from heat from the sun.

There is general puzzlement by the building users about the location of the different kinds of solar shading in the school building, for example why there sometimes is no shading on the north-facing windows. Even though the north façade of the school is not affected by direct sunlight during the school day, it does require darkened rooms for powerpoint presentations. This has raised questions about the understanding of the users' needs during the design process. One interviewee said that "There should have been more user involvement" in order to understand what the teachers and pupils need. We have been told by the actors from Skanska and Trøndelag county council that there was a user participation process, and experience with other building projects tell us that this is common in public buildings. However, the building users' comments about the process around the solar shading and daylight requirements implies that the participation process was limited, and when in doubt expert advice was followed rather than following up requirements from building users.

The windows with EG shading are divided into 2 fields, a large one at the bottom and a smaller one on top. It is rare that both fields are working simultaneously, and it makes it more complicated when the technical management is trying to find out where the problem is. If this division was chosen on purpose or if it is a technical necessity could not be answered by the technical management.

> "The division into two fields seems unnecessary. It would be a simplification and would remove a source of error. Why are there two parts? Is it because of the season and the height of the sun?"

The interviewees told us that they had complained a lot about the slow or non-responsive shading system (windows that either did not darken or were dark all the time). One of them said that there must be a lot for the head of the technical management team to deal with because "everyone was complaining to him". There was therefore understanding among building users that the problems with the window shading were a system problem and not the fault of the technical management team, but they were frustrated since problems with the solar shading had a negative influence on their workday.

> "I complained and complained, and eventually something did get done. I was so happy, but it didn't last long (the windows stopped working again). It's okay to say something once or twice, but you expect something to happen. It's fair enough that something doesn't work in a new building, but it must work eventually."

There have also been problems with external sun protection on the other floors, but fewer problems than with the EG system, however. A sun shading system that works is essential in a school. The most serious problems with the EG system that the users reported to us are,

- Repeated system failure: Informants described a system that was not working when the school opened and only worked according to the original specifications for two months, before the system failed again.

An interviewee told us "We repaired it and it worked for a couple of weeks and stopped working again. I'm very dissatisfied. I can't use the office between 8-10. It's gets too hot and I can't see the computer screen."

- A lack of local knowledge: the technical management team has received no training, and there is no clear description of which window with EG is connected to which circuit.

A member of the technical management told us "it could have been clearer in relation to what room it is in. What circuit. There is a drawing, but it is convenient to know which circuit."

- The system expert comes from abroad.

> Building user "The worst thing about it is it takes so long to get help. You lose faith. It is probably similar to the technology in car windows. They should already know how it works. If they are going to test it, there must be someone living nearby. It shouldn't be necessary to fly an expert in from abroad (the interviewee was absolutely sure the expert was from abroad). They should train up someone in Trondheim."

- There are practical challenges due to a lack of solar shading. A number of rooms have already had internal roller blinds installed.

> "A school doesn't just need sun protection. It must also darken for presentations. The use of PCs and presentations are common in schools today, and a 20-minute-long response time is too slow. For some reason the narrow windows work faster. We have to go to the classroom and turn on before the lesson begins."

- Users are not getting help. This includes both building users who use offices and classrooms and the technical management.

> Technical management "This is one of the rooms we are least satisfied with. It just flashes and I don't know why. I don't know enough about it. We don't know really how it should be run. A lot of people think it should be darker. No one has training and equipment. This is a pilot project, and the support is poor."

3.2 Positive aspects

All the informants had previous experience with working in school buildings. They based much of their response and their expectations about Heimdal vgs. on this experience. For example, one of the informants stated that the school

> "is a large area that needs to be regulated. I've worked at a school before. Temperature is always a challenge. It is not different here."

They were therefore not surprised when things did not work, and there was no indication that they were looking for things to complain about. There were qualities about the EG system that they were positive to. For example, aesthetic qualities. One of the informants told us that when the EG system was working it was still possible to enjoy the view when the sun was on the building, and she also considered the system stylish or smart. It looks nice in the new school building. External sun shading is much more visible on the building, and there is a limited or no view out of the window when the shading is down.

According to technical management the fact that the electrochromic system has no external mechanical elements which can be damaged by the wind is positive for maintenance,

> "It does not need any service or lubrication when it is working."

The EG system clearly has advantages in some settings. In classrooms, however although aesthetic qualities are important, they do not weigh up for the inconvenience caused by the sunlight hitting screens (glare), the slow response time for activation, and overheating. The idea that EG will not need maintenance is also positive, but the amount of system failure means that the technical management has been unable to enjoy this quality yet. The EG shading system seems to require an extra internal shading device that is quicker to apply in settings where immediate response to sunlight is needed.

4. Results from daylight measurements

The measurements are presented as daylight factors (DF) and are stated without and with the shading systems activated.

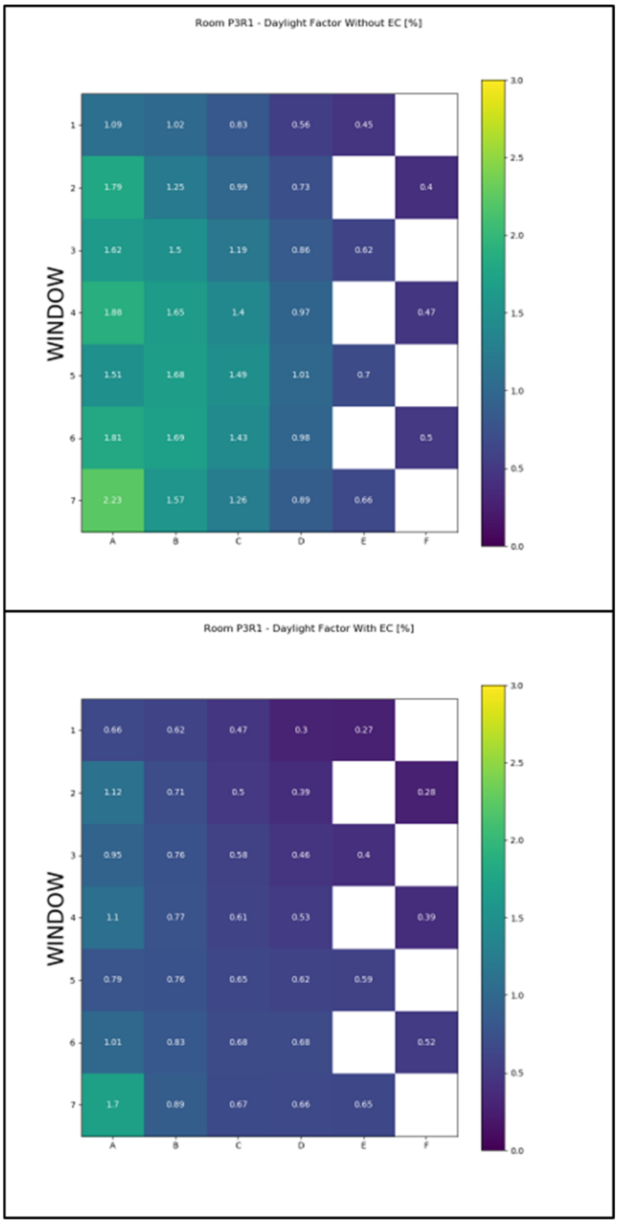

Figure 1 Daylight factor for room P3R1 without EG (top) and with EG (bottom)

Figure 1 shows the daylight factor for room P3R1. However, the EG window was not working properly. It was not possible to reach a fully tinted state (this can also be seen when comparing with the measurements from the other rooms). The measured average daylight factor in the room is approximately 1.16 without the activation of the EG and 0.67 with the EG (partially tinted) activated.

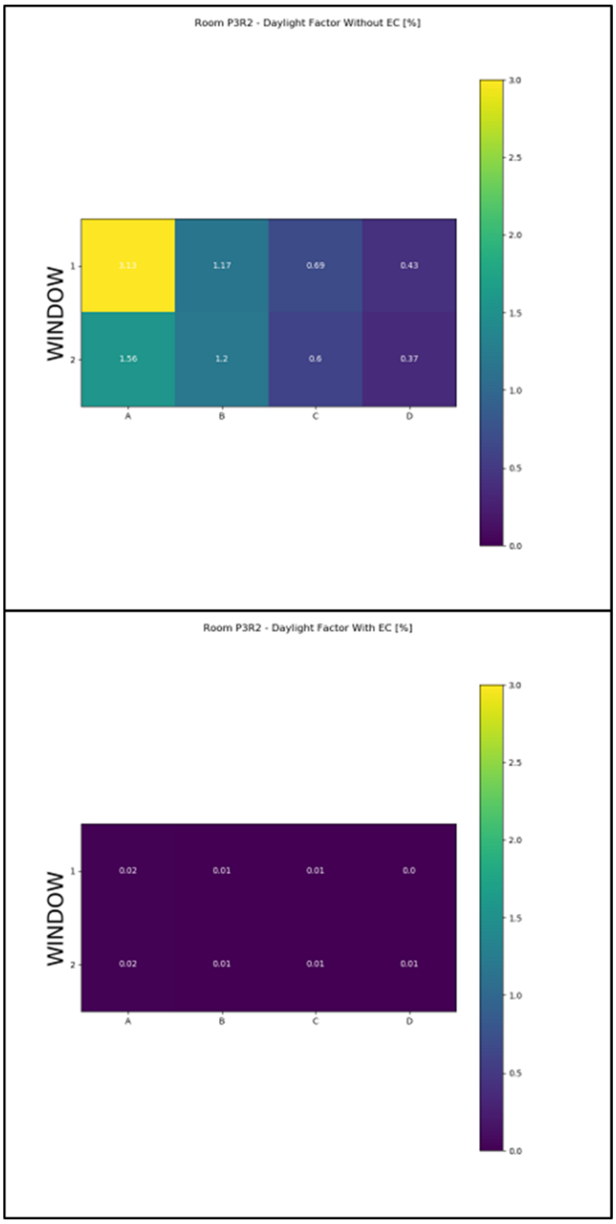

Figure 2 Daylight factor for room P3R2 without EG (top) and with EG (down)

Figure 2 show the daylight factor distribution for the office space P3R2. When the EG windows were activated the room was rather dark, giving a very low measured daylight factor.

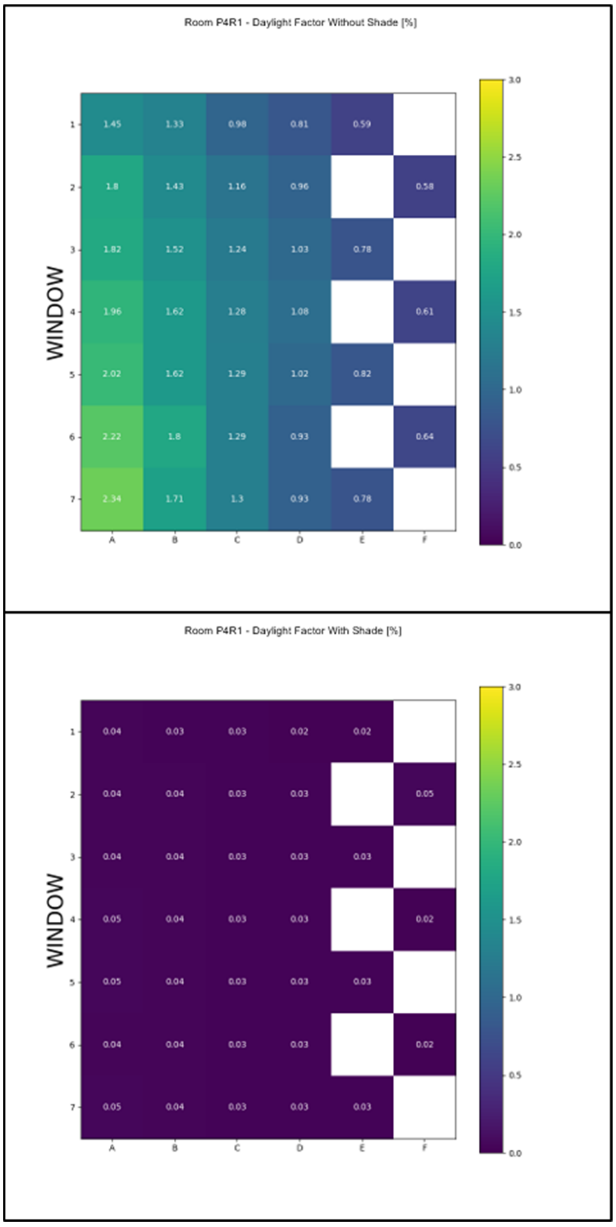

Figure 3 Daylight factor for room P4R1 without shade (top) and with shade (down)

Measured daylight factors for P4R1 are presented in Figure 3. The room is placed directly above P3R1 and has similar dimension. The average measured daylight factor with screens in retracted position and deployed screen are 1.27 and 0.03 respectively.

- The average values of the daylight factor with and without the activation of the EG glass are app. 0.01 and 1.14 respectively.
- Comparing the average values of P3R1 and P3R2, both equipped with EG glass, it becomes evident how the daylight factor without the EG activated is similar. With EG activated in the same rooms, the average DF were rather different. This confirms the visual observations of the malfunction of the EG system in P3R1.
- Measured daylight factors in rooms with EG-shading and in rooms with external screen were in the same order of magnitude, when the shading is active and non-active.
- EG provides a better view to the exterior when activated compared to screens.

- We also encountered technical problems in one of the rooms with regular shading (room P4R2). It was not possible to lower the external screen due to a malfunction.

5. Conclusions and recommendations

The EG technology is promising, however with an EG system integrated in the glazing unit, no externally mounted shading is in theory required. This is something many architects and users see as a positive feature. EG can provide users with an exterior view when activated. This is blocked when a traditional screen is used. In addition, EG have no moveable parts. Potentially causing less maintenance. However, major technical issues and malfunctions were experienced at Heimdal vgs. This must be seen in connection with the negative feedback from the users. However, all repair-work is done from the inside, with no need to use a lift outside.

Solar shading is important within the physical context necessary for educational purposes – classroom systems are becoming more technically complex, and façade systems can perhaps be expected to be more complex. However, much of the technology found today in classrooms requires individually controllable lighting – computers and smart boards do not work well when used in combination with direct sunlight. Powerpoint presentations require darkened classrooms and the possibility to quickly change from a dark to a light room.

Based on the users' perception of the EG system at Heimdal vgs., we do not recommend EG as the only shading system in rooms intended for educational purposes. The user evaluation process gives a clear indication that EG did not support the use of classroom technologies and therefore limited classroom functionality. This could be addressed by mounting additional internal shading devices that can reduce the daylight levels and glare issues. The EG should be used for controlling the solar heat gains to reduce heating and cooling demands. Visual aspects relating to glare and black-out control could be solved with internal shading devices.

EG did not function well in individual offices, shared office spaces, or group rooms. Sunlight on screens (glare) and overheating were experienced due both to the slow response of the system to sun on the windows and to repeated system failure. A solar shading system that is unable to respond immediately to the needs of the building users limits the building`s functionality and should not be used as the only shading system in a school.

Even when functioning as intended, EG is unable to remove all glare and does not have the necessary short response-time when switching from light to dark. The technical quality and the systems for control and operation of the EG system were somewhat poor. In a newly constructed building, the failure rate of the EG-units as high as found at Heimdal vgs. is not acceptable. Additionally, proper training and instructions for maintenance personnel and other building users should be given for all types of technologies. The fact that there was a malfunction of the traditional solar shading device (zip-screen) in one of the rooms points to similar challenges and improvement needs for the traditional shading system. External solar shading screens in the offices and classrooms exposed to direct sunlight should be considered unless the technical quality of EG is improved. Lastly, internal shading is recommended in addition to EG for glare and daylight control issues in all rooms where there is a need to darken the room.

A user evaluation process is useful to gather feedback after a building has been taken into use and is relevant in a project such as Heimdal vgs. which is a pilot project and where innovative building technologies have been introduced. The process is a source of stories about the successes and failures associated with advanced building systems. At Heimdal vgs. the EG system has not received a positive evaluation, and it is not recommended for use in school buildings. EG's story is therefore not a success story, it is a "learning story" (Janda and Topouzi 2015). It points to the challenges associated with use. There are a number of issues in the report that should be shared with the construction industry, thereby helping to avoid similar problems in other buildings. There is much to be learnt from the challenges experienced at Heimdal vgs.

A summary of problems with EG in Heimdal secondary school,

Classroom problems

- Slow response time of EG– up to 20 minutes - means little flexibility and extra planning for staff
- Malfunction of several windows with EG
- Even though low DF's were measured, users complained that rooms were not dark enough for powerpoint presentations. The measurements indicate that this could be due to malfunction in some of the EG-windows (not able to dim fully or some glazing units not functioning at all) or because the system is only active when there is direct sunlight on the window.
- Sunlight on computer screens (glare)
- Solar heat gains increase indoor temperatures more than with regular screens as shade according to users

Office problems

- Slow response time, no quick adjustment to changing weather conditions.
- Malfunction of several windows with EG
- Limited personal control (varied if there were switches or not).
- Small rooms: difficult indoor climate because of heat. Windows have to be opened all day.
- Sunlight on screens (glare)
- Sunlight in eyes during meetings (glare)

6. Literature

Byggforskserien, 421.626 - Beregning av gjennomsnittlig dagslysfaktor og glassareal. SINTEF Byggforsk, 2004.

Dussault, J.-M. and L. Gosselin, Office buildings with electrochromic windows: A sensitivity analysis of design parameters on energy performance, and thermal and visual comfort. Energy and Buildings, 2017. 153: p. 50-62.

Janda, K., Topouzi, M. 2015 Telling tales: using stories to remake energy policy. Building Research and Information, 43:4, 516-533, DOI:1080/09613218.2015.1020217

Pink. S. 2015 Doing Sensory Ethnography. Second edition. London. Sage.

Skinner, J. 2012 The interview: An ethnographic approach. Oxford. Bloomsbury.

Tällberg, R., et al., Comparison of the energy saving potential of adaptive and controllable smart windows: A state-of-the-art review and simulation studies of thermochromic, photochromic and electrochromic technologies. Solar Energy Materials and Solar Cells, 2019. 200: p. 109828.

Vermeeren, A., Lai-Chong Law, E., Roto, V., Obrist, M., Hoonhout, J., Väänänen-Vainio-Mattila, K. 2010 User Experience Evaluation methods: Current State and Development Needs. Proceedings: NordiCHI 2010, October 16-20, 2010

VISION:

«Sustainable neighbourhoods with zero greenhouse gas emissions»

Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

https://fmezen.no