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Electrochromic Glass system in Norwegian Climate: Control strategies and Impact on the indoor thermal conditions.

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Abstract. This work investigates by simulations the impact of the use of Electrochromic (EC) windows in a modern wooden cabin with large window area in a colder climate. The climatic areas considered are 4 different locations in Norway. Three different automatic control systems were used and compared. The windows were alternatively equipped with a textile integrated external blind and an EC glass. The results show that the use of EC glass has a quantifiable impact in term of reduction of peak temperature by 2°C and reduction of number of hours with high indoor temperature. The control system that seems to perform better is based on external solar radiation. In the particular situation of a cabin, where the visual comfort and the surrounding view has the greatest importance, a more complex control algorithm needs to be developed.

1. Introduction

The need for improving the energy efficiency of buildings, together with a growing interest towards the wellbeing and the comfort of occupants, has led to the study and implementation of chromogenic materials in the transparent building envelope. The term *chromogenic material* indicates all those materials whose optical properties can change when they are subject to environmental conditions or external stimuli such as temperature, pressure, humidity, light, gas exposure, electric field, etc. [1] When the regulation is achieved by applying a small DC voltage at the glass, the device is indicated as electrochromic (EC). Traditional methods for controlling the amount of light entering a space, such as shades or blinds, generally block the view as well, and in addition might offer few and/or complicated control strategies. EC windows provide a light control solution while leaving a view of the surroundings [2,3]. Scholars who have studied EC windows, or smart windows in general, concentrate on two main aspects: the energy saving resulting from spectral modulation and the optimal use of daylight, the latter involving both visual comfort and the eventual savings on the cost of using artificial lighting [4]. These two aspects can also conflict during the operation of these devices. For example, during the winter months, an energy saving strategy would tend to keep the glass in its bleached state and let the solar radiation enter the building, but the low angle of the sun can give rise to consistent discomfort due to glare [5]. Sibilio et al. [6] provided a very interesting review on the studies conducted on EC windows together with an overview of the most widely available commercial technologies and the theoretical and experimental works published in the last decade. According to their review, an EC windows can allow energy savings up to 59% when compared to a traditional solution. Nevertheless, the real benefits do not directly come from the peculiar characteristics of the product, but rather from the orientation, the climatic conditions and above all the control strategies that are applied. Also according to Jonsson [7] the link between the EC and its positive effect on the energy consumption is represented by an optimal control strategy. The control logic of such devices cannot be generalised, but as Cannavale et al. [4] point out, it needs to be adapted to the device features, the building use, the climate and the exposure. Several scholars have investigated possible control strategies and tried to evaluate their impact. In one of the first attempts a control based on an illuminance threshold was adopted [8] and resulted very effective in the reduction of the energy consumption. Gugliermetti and Bisegna [9] proposed a control based on both thermal and visual aspects.

These works were all taking into consideration buildings located in warm climate, where the energy consumption is cooling driven. When buildings are located in Northern climate, where cooling



request is negligible or not even available, the saving in energy obtained by the use of Smart Windows become less important. Other aspects, such as the visual comfort, become prevalent. As aforementioned, the EC devices and the Smart Windows in general, are seen as an alternative to traditional solar shading system. Nevertheless, due to the constructive characteristics of the two, there is no limit to the simultaneous use of the two systems. Lee et al. [10] proposed a solution with EC glasses and venetian blinds, which is stated to be effective although representing a costly solution. Zinzi [5] also mentions this solution in his work where he concentrated on the occupants acceptance of such systems.

This work explores by means of simulations the effect that EC windows would have in a particular context, namely a log cabin in an open environment. This kind of constructions are especially used in Northern Europe as holiday houses, for a limited period of time and normally not as dwellings. It is because of these characteristics that the energy consumption aspect becomes secondary. In addition, the occupancy is especially high on summer, and in colder climates is not common to have a cooling system installed. Therefore, this paper concentrates on the capacity of EC devices to reduce the internal temperature in warm days and to assure a better visual comfort intended both as glare avoidance and the possibility for the occupants to have a view of the surroundings.

2. Methods

The calculations were performed by means of Building Energy Performance (BEP) simulations using the software IDA-ICE. The parameters which were considered were the geographical location of the cabin in Norway, the type of screen (No screen, traditional textile, and EC) and the control strategies. All these parameters were combined for a total of 36 BPS cases, each one simulated over a period of a whole year.

2.1. Numerical Model

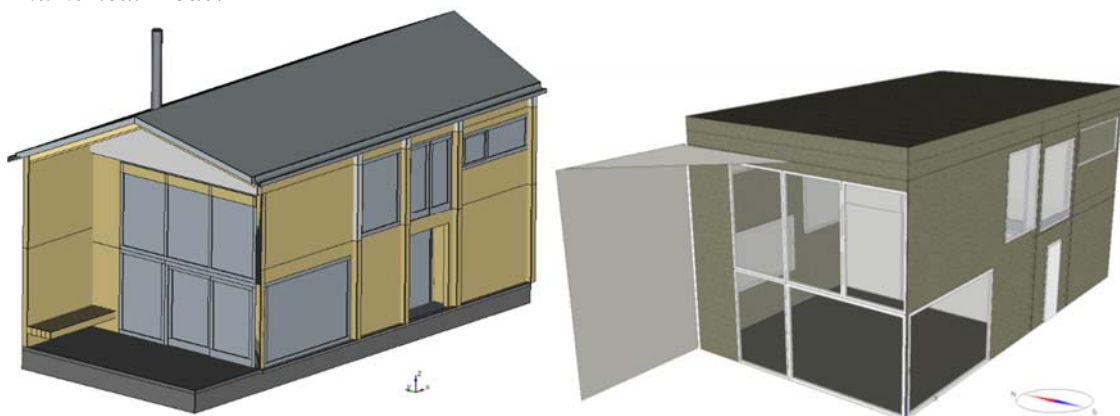


Figure 1. IFC model of the log cabin (left) and IDA-ICE model (right).

Figure 1 shows the BIM model and the corresponding IDA-ICE model. The model was prepared based on the BIM files provided by a construction company. The windows exposed to South and West were considered of interest for the installation of shading devices or EC devices. The cabin is developed on two floors. Roughly half of the internal volume is reserved for a large living room which spaces over two floors, and which is constructed with a very large windows area. The rest of the space is constituted of small rooms or utility rooms, as typical for this kind of cabins. Because of this, all the analysis of interest and the results here presented, always refer to a single thermal zone constituted by the living room. The small porch at the entrance is simulated by a shading object (in grey in Figure 1). In the real cabin, both external and internal walls are realised with intersecting wood logs. In the calculations these are modelled as a 155 mm thick continuous wood wall (U-value $0.783 \text{ W/m}^2\text{K}$). The basement of the construction is concrete (thickness 210 mm).

The open country wind profile was chosen for the simulations as it is the typical location of such constructions. Four different climates were chosen to represent different climates in the country, namely the weather files of Kristiansand, Oslo, Trondheim and Tromsø.

2.2. EC and Textile Screens

To evaluate the impact of the EC windows, each case was simulated when the windows were equipped respectively with no screen, traditional integrated textile screen and EC windows. The possibility of simulating an EC device is not yet available in the code and the EC devices have to be modelled as integrated shading systems. According to the control signal, a part of the window is in its darkest state (usually the top) and the other in its brightest. Nevertheless, previous work demonstrated that for the energy state of a zone (i.e. a room), the situation in which a portion of the window is in its darkest state while the other is in its brightest, well approximates the intermediate states of the EC glass [11,12]. In the code the screens are modelled as a set of multiplying coefficients which are applied to the window parameters. Those used for this research are reported in Table 1. The values for the traditional textile screen were taken from IDA-ICE database, the values for the EC devices were calculated comparing the bright-state and dark-state characteristics provided by a Smart Window producer.

Multiplier	Textile Screen	EC glass
g-value	0.31	0.67
Tv	0.19	0.53
U-value	0.77	1
Diffusion factor	1	1

Table 1. Multipliers used to simulate the textile integrated solar screen and the EC glass.

2.3. The control

Three control strategies were used, based on the most common cases found in literature. As reported in the introduction, many researchers have tried to identify the optimal control strategy but almost all the publications refer to warm climates and office building. It was not clear a priori what strategy must be considered for a discontinuous dwelling in a cold climate.

The first control strategy to be considered was the *operative temperature control*. The code calculates the operative temperature of the main room at every time step, and this value is taken as a feedback signal for a controller that operates the screen. This strategy is used in warmer climates for the purpose of cooling energy saving. The threshold was taken at 26°C.

The second strategy, the *illuminance control*, is based on the illuminance calculated on an ideal plane at 80 cm from the floor. This is a common strategy used in office buildings to avoid discomfort. In this case the threshold was set a 2000 lux, considerably higher than the one used for office buildings.

The last control strategy is instead based on the value of the incident *solar radiation* on the window (and more in general the outer wall). Those EC glass producers who also offer an automated control, usually offer this solution. The threshold in this case was 200 W/m² and it was chosen considering both values found in literature and the default settings of commercial products.

All the controllers calculate the signal as a value between 0 and 1, where 0 represents the absence of solar screening, and the 1 represent the total deployment. All the values in between represent the fraction of surface covered by the screening system. In the case of the EC, it would ideally represent the advancement of the darkening state, but as explained before at this stage of the simulation there is no difference between the modelling of the two shading systems.

3. Results

3.1. Operative temperature control

Figure 2 reports the internal operative temperature when the operative temperature control is in use. The blue line is the outdoor temperature, the green line the indoor operative temperature when no screen is used, the red line when the screen is a traditional integrated textile and the yellow line when the screen is an EC glass. In black and purple are reported respectively the control signal of the textile screen and the control signal of the EC glass. The period is a typical summer week for the considered climate zones. The diagram shows that the screen is not in use every day and when it is it is used for a limited time in the middle of the day. It is also worth noticing that in the considered week, the climate file for Trondheim did not report high temperatures or particularly sunny weather, therefore the screen operation is almost absent. Considering the case of Oslo between July 31st and August 1st, it is possible to see a several hours long period in which the screen is used. In this period it is possible to evaluate what is the decrease in the internal operative temperature caused by the different screens. The EC glass is able to reduce the temperature of circa 1°C, while the textile screen up to 2.5°C. This result was expected.

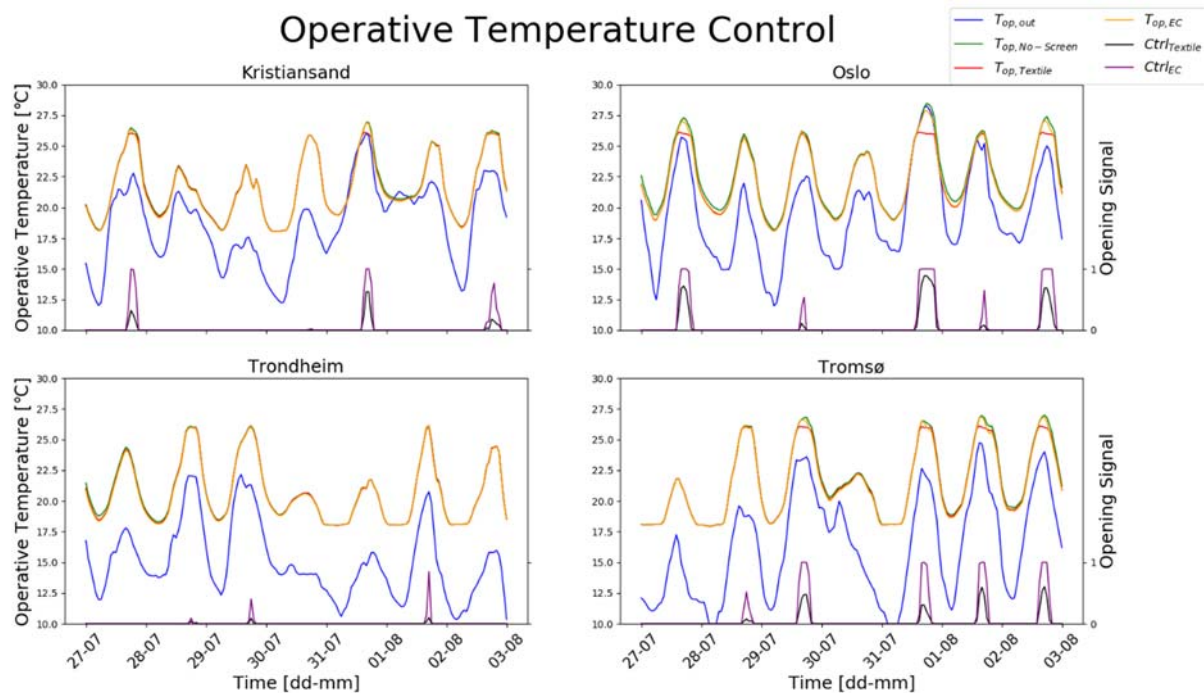


Figure 2. Internal operative temperature when the operative temperature control is used for a typical summer period.

3.2. Illuminance control

The results in terms of indoor operative temperature for the control strategy based on illuminance control are reported in Figure 3. In this case the screen is activated every day. As indicated before, the threshold for the illuminance control was set at 2000 lx and, according to these results, it seems to be too low. Nevertheless, the results are reported since they are useful to evaluate the impact of the screens on the operative temperature for different situations. It is also worth noticing the case of Tromsø between July 30th and July 31st. Here the outdoor temperature falls, but the screen is still deployed for the whole day. This can represent a flaw for this control strategy.

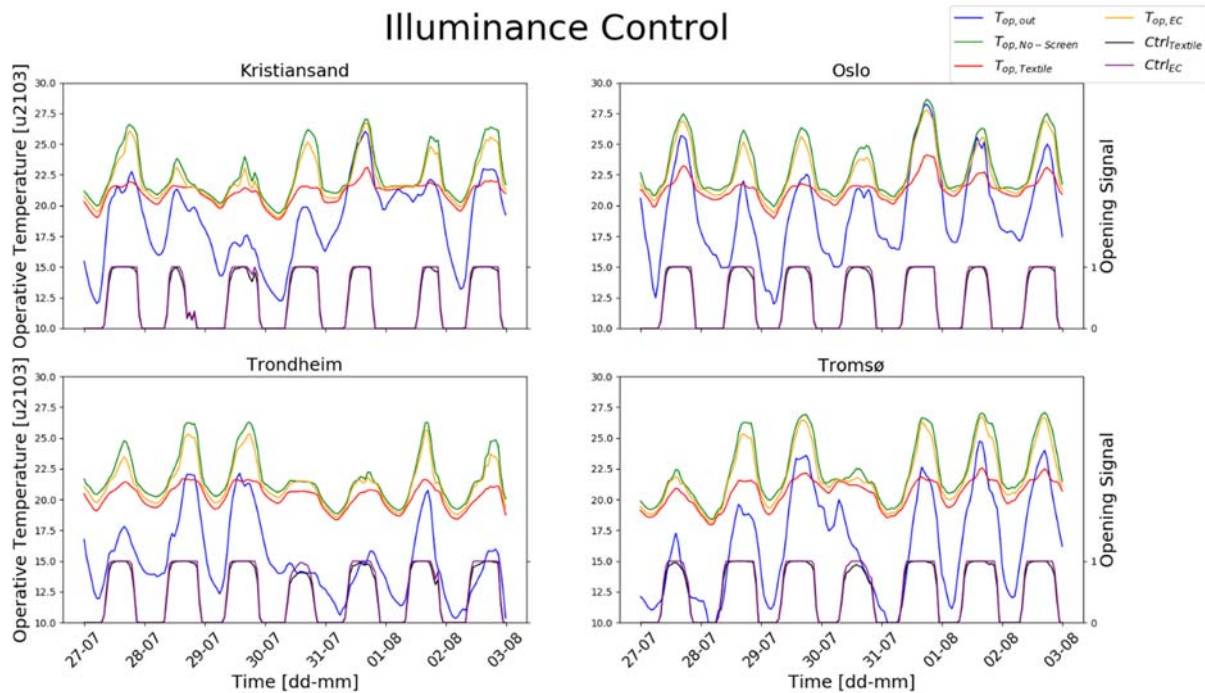


Figure 3. Internal operative temperature when the illuminance control is used for a typical summer period.

3.3. Solar radiation control

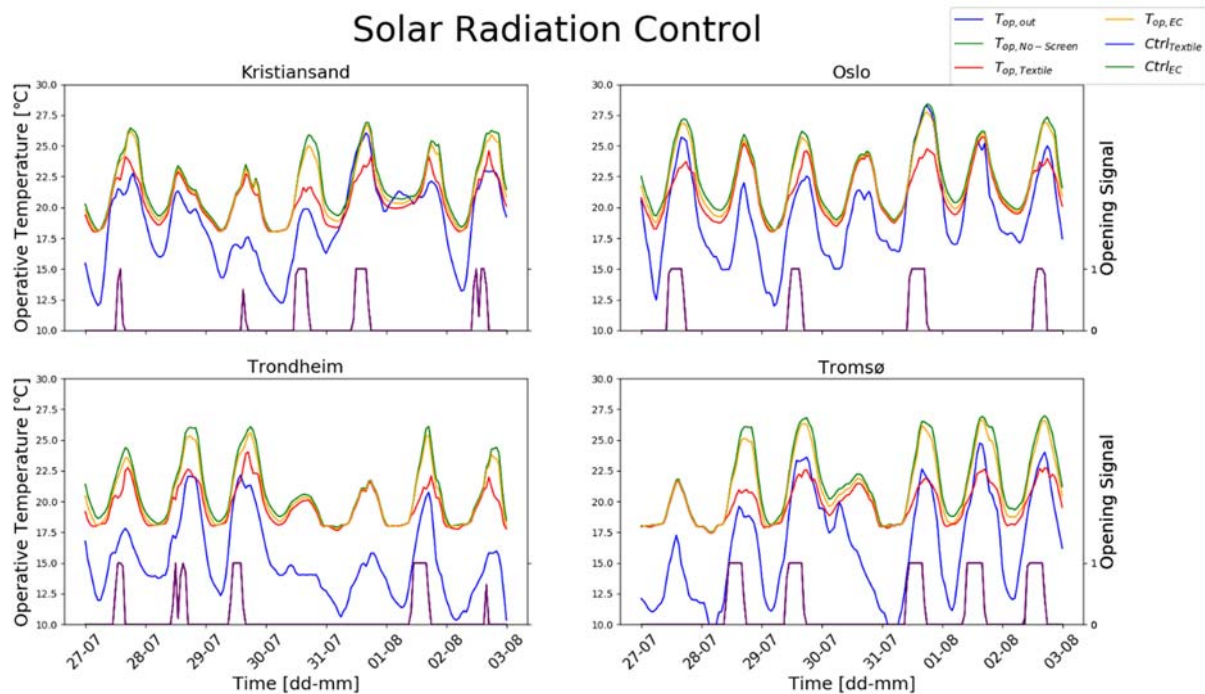


Figure 4. Internal operative temperature when the control is based on the normal incident radiation on the facade.

Figure 4 presents the result in terms of internal operative temperature when the solar radiation control is in use. Being the control based on an external measurement, it is not influenced by the action of the

screen, hence the control signal is the same for both the devices. This system seems to perform better than the other two: the screens are in use for a longer period if compared to the operative temperature control, without intervening every day in spite of the outdoor conditions as it happens in the case of illuminance control with a low threshold (cfr. Figure 3). It is also possible to notice that the decrease of the operative temperature is more consistent. The control, in fact, uses as a reference value a parameter which is not influenced by the deployment of the screen and, eventually, it is what causes the temperature increase. Therefore, the control seems to act in a way that anticipates the overheating, rather than trying to counteract it once it is happening.

4. Discussion

The two aspects that are most relevant for the application of innovative solar shading system in this context are, as explained, the reduction of overheating in summer and the visual comfort rather than the energy saving. For the first aspect the results shown in Figures 2-4 give some overview. The traditional integrated screen is more effective than the EC glass in reducing the peak temperature, but the EC glass has in any case a sensible impact. For what concerns the visual comfort, it is difficult to state its impact. A thorough study would require the evaluation of the glare in the room, but in this situation this would not be possible. In fact, due to the way EC windows are modelled, a certain area of the glass in its dark state, while the other is in its bleached state according to the control signal. This would cause a contrast in the illuminance levels in the room and lead to glare effects that would not happen in the case of a real EC glass whose whole surface changes its optical characteristic at the same time. This, together with the possibility of having an external view, are indeed the most noticeable advantages of an EC based shading system.

This said, the analysis of the internal calculated illuminance, although not fully adequate to evaluate the visual comfort in the room, can still give valuable information. And this especially for what concerns the effectivity of the control systems. Therefore, the illuminance level of two of the systems (operative temperature and radiation based) were analysed for the two extremes of the considered climate zones: Kristiansand and Tromsø.

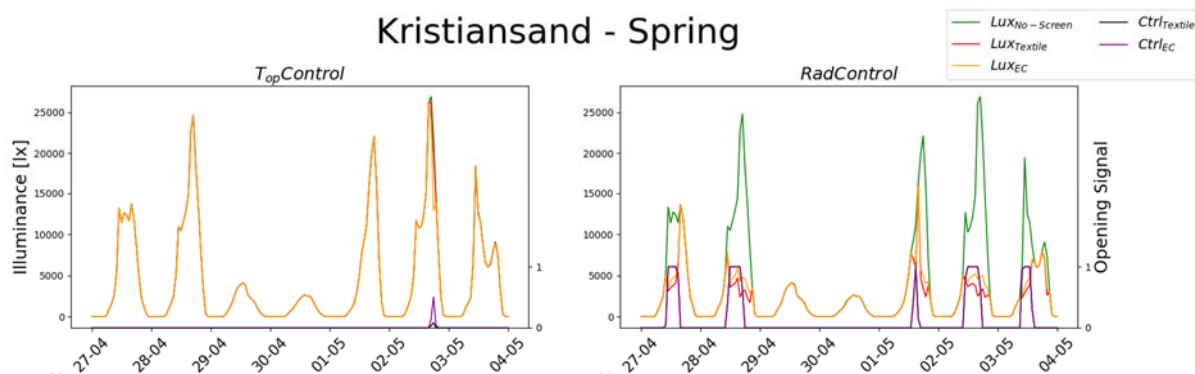


Figure 5. Comparison between the operative temperature control and the solar radiation control in Kristiansand in spring.

Figure 5 shows what happens in Kristiansand in the spring. Spring in Norway can be very bright, especially when there is still snow on the ground, but the temperature is normally quite low. The result, as we can see, is that the shading system is almost never deployed when the operative temperature control is used. This causes a high level of illuminance in the room which will possibly lead to glare and visual discomfort. The solar radiation control seems instead to be able to act against this. The same situation happens in Kristiansand in the autumn, as shown in Figure 6. The reduction of the illuminance level is large, and both the textile and the EC glass have a similar impact. The textile screen, as expected, have a stronger capacity to reduce this value, but the final illuminance is

comparable in the two cases, thus suggesting that when it comes to glare avoidance, the effectivity of the EC glass could be not far from the one provided by the textile screen.

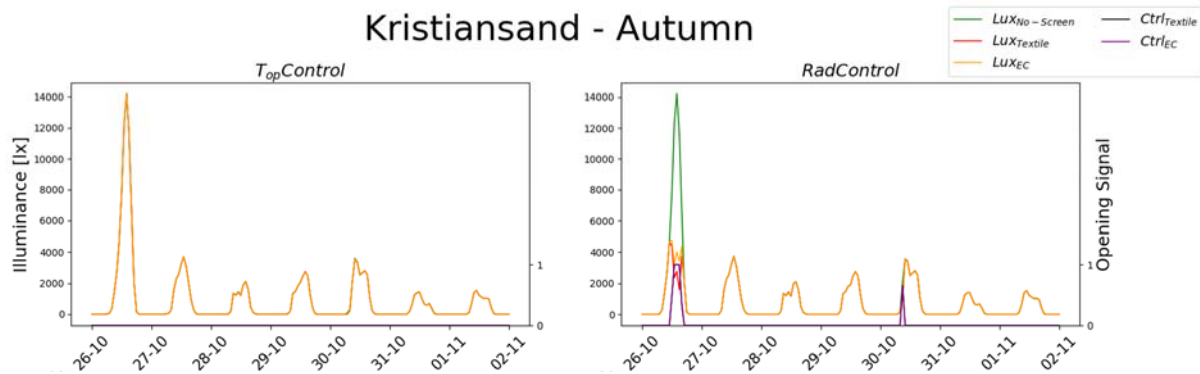


Figure 6. Comparison between the operative temperature control and the solar radiation control in Kristiansand in autumn.

Another interesting case is when the Tromsø climate is adopted. The city is located in the North of Norway and has a peculiar climate. Winters are dark and the sun does not rise for weeks, while part of the summers are marked by midnight sun. Winter temperatures are low, but not as much as other locations at the same latitude in other parts of the world. On the contrary, summer temperatures are rarely high. This leads to an autumn case which is analogous to what happen in Kristiansand (cfr. Figure 6). In the summer, the operative temperature control seems to be effective in reducing the peak temperature (cfr. Figure 2), but by analysing Figure 7 it is clear that the same system would not be able to act towards an increase of the visual comfort.

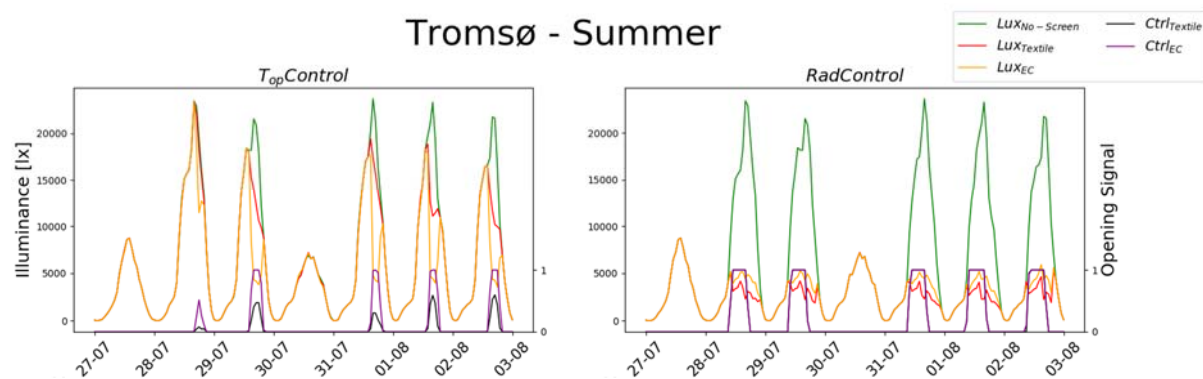


Figure 7. Comparison between the operative temperature control and the solar radiation control in Tromsø in summer.

5. Conclusions

The impact of two different solar shading systems applied to an isolated mountain cabin in 4 possible locations in Norway was evaluated by means of BEP simulations. The traditional integrated blinds seem to perform better against the overheating, as largely expected, but the EC glass demonstrated to be able to give a valid contribution. When it comes to glare avoidance, as explained, this is beyond the results presented in this paper. Nevertheless, as the simulation results suggest, the illuminance level reduction in the room by the EC glass seems to be comparable to the textile screen, although slightly inferior as expected. In that case, though, it must be considered that the EC glass has the advantage of having uniform characteristic on the whole surface.

For what concerns the control systems, all of them have demonstrated some criticalities. The operative temperature control seems to be able to contain the overheating (important in a situation

where no cooling system is present) but does not seem to be able to work towards an improvement in the visual comfort. The illuminance control could work in this direction, but it is triggered without considering the operative temperature in the room, and this can represent a problem for the winter months. In addition, the determination of the threshold is not trivial. The solar radiation control seems to work better, but a further evaluation needs to be performed.

As the considered climates provide very different conditions throughout the year, it is likely that a simple control system will not perform well. A more complex system must take into account the period of the year (with relation to the sun position on the horizon) the outdoor temperature and especially the occupancy, being these cabins used as holiday houses and not dwellings. A more complex system is being studied at the moment, with contributions from laboratory measurements, and with the inclusion of occupants in the experiments. The results will be presented in future works.

Acknowledgements

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