A case study addressing the benefits of daylighting and electric lighting integration in the retail sector

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Abstract

This article describes field monitoring and supplementary simulations of an existing daylighting and electric lighting integrated design for a furniture store. First in its type, the store includes several areas of the showroom provided with abundant daylighting. For the monitoring, the areas of the living rooms and the home decoration exhibitions were selected. They include wide glazed areas, daylight harvesting systems, and tunable lighting. The monitoring procedure assesses four aspects: energy use, objective or measurable lighting conditions, circadian potential, and subjective evaluation of lighting. The results suggest that the integration project was successful in terms of energy saving, as well as customer and staff appreciation. The customers were more attentive to daylighting; they also report a better shopping experience compared to equivalent shops. Staff showed satisfaction with the electric lighting solutions, for example with LED panels with automatic tuning of correlated color temperature. For future projects, the article argues that daylighting in furniture shops may be an asset. In addition, for the methodological part, the monitoring suggests that objective and subjective evaluations should be always combined for a full understanding of the integrated project.

Key-words: daylighting; electric lighting; lighting controls; integration; human centric lighting; energy saving.

1. Introduction

Retail and wholesale sector represents 11% of the GDP and employs 15% of the workforce in the European Union (Eurostat, 2015). Lighting accounts for 50% of the energy use in non-food retail stores (Jamieson, 2014; Euro Commerce, 2018), thus a huge potential exists in energy savings for lighting of retail buildings. Designing for daylighting and electric lighting integration is fundamental to obtain energy savings, as well as healthy and satisfied occupants. Literature investigates the multiple benefits of integrated solutions (Baker et al., 2013; Edwards et al., 2002), but objective monitoring of exemplary real-world projects is rare. Given that case studies are usually effective and persuasive for bringing knowledge into action, the recently launched IEA SHC Task 61 / EBC Annex 77 Subtask D, which aims at demonstrating the benefits of integrated lighting solutions by monitoring exemplary projects. More information can be found on http://task61.iea-shc.org/.

Although e-commerce in general grew by 96% between 2013 and 2018 in Europe (EuroCommerce, 2018), 59% of customers still prefer to buy their furniture in-store (Ecommerce Foundation, 2018). Physical furniture stores will hardly disappear in the next future and it is important to exploit their energy saving potential, while increasing the customer experience. In this paper, we report on a peculiar case study, a pilot furniture store opened in Germany in 2018 with the aim of testing daylight integrated design as a new strategy for the chain new store openings and retrofits. The solutions include skylights, wide windows with automated blinds, combined with daylight harvesting and tunable electric lighting. The aim of this integrated design was to provide an attractive environment to customers, while saving energy. The approach is quite innovative; indeed, lighting design in the retail sector tends to rely mostly on electric lighting, which is easy to control in terms of intensity, distribution, and color. The use of daylighting introduces a number of opportunities and threats to a typology of store and clientele so accustomed to the "closed box". This study seeks to evaluate this integration in the project as a whole, by combining technical measurements with observation of the customers and staff, aiming to identify the multiple benefits of daylight integration. The final objective is to understand to what extent integrated lighting solutions can save energy and improve the shopping experience in this type of shops.

2. Methodology

The evaluation of the integrated lighting design for the selected areas follows a monitoring protocol which is

Selection and/or peer review under responsibility of Scientific Committee
doi:10.18086/swc.2019.38.02 Available at http://proceedings.ises.org

currently under development in IEA SHC Task 61 / EBC Annex 77 Subtask D. The monitoring protocol requires on site measurements of 1) energy for lighting (and heating and cooling), 2) photometric aspects, 3) circadian aspects of lighting, and 4) users' opinion. When on site measurements are not possible, the protocol allows for calculations.

A key feature of the protocol is the combined use of so-called Technical Environmental Assessment (TEAs) (or objective measurements, with technical instrumentation) and Observed-Based Environmental Assessments (OBEAs) (or subjective measurements, usually with questionnaires or interviews) (Craik and Feimer, 1987). One of the reasons to combine TEAs and OBEAs is that a full evaluation based only on technical instruments would be difficult, resource-consuming, and, most importantly, limited. Cross-evaluation with longitudinally-designed OBEAs, instead, highlights aspects that are often impossible to be measured in reality, especially with few point-in-time TEAs or at the individual level (O'Brien et al., 2019). More information on the current version of the protocol are provided by Gentile and Osterhaus (2019).

The monitoring was done during three site visits during spring 2019, each visit lasting for about one week. The purposes of the first visit, which was shorter, was to get acquainted with the building, the lighting systems and the staff, also, two areas were selected for monitoring. The following visits were planned around the spring equinox and the actual monitoring, described in the following sections, was carried out at that time. The field monitoring provided input information, e.g. geometries and photometry, for the calibration of supplementary daylight simulations and energy calculation. These were needed when practical conditions did not allow for a befitting field evaluation; for example, the daylight autonomy (DA) can be measured on field only with a one year logging, and ubiquitous and intrusive illuminance sensors – which cannot be installed in a shops.

2.1 Geometry, lighting solutions and selection of monitored areas

The case study is a furniture store of a global chain located in Kaarst, Germany (latitude 51° 13′ N). Overall, the store appears similar to other stores of the same furniture chain; two blocks of rectangular geometry, one for the exhibitions and the other for the warehouse with self-serve collection. The entrance and the restaurant typically articulate the connection between the two blocks. The Kaarst store is provided with generous glazed areas in both blocks. In the exhibition block, windows are positioned in strategic locations along the façade. In the warehouse block, daylighting is guaranteed by skylights and full-height windows at the end of every aisle. Some windows on the façade are equipped with movable rollers, but the latter are always left in fully open position.

The electric lighting is provided with daylight harvesting control in some of the daylit areas, while LED panels with tuneable correlated colour temperature, CCT, (here called Human-Centered Light, HCL) are installed in two of the showroom areas, in the cash-line and in the employees' canteen. The remaining luminaires are highly efficient, but they are not specifically integrated with daylighting (Table 2).

The spaces in the store of interest for this study were selected during an initial visit in February 2019. The selection first identified the areas with high daylight availability; among those, it prioritized those with electrical lighting integration. A SWOT analysis based on plans and documentation, as well as on discussion with the store staff and facility management team, identified two area to be monitored as in Table 1.

Tab. 1: SWOT Analysis of the selected daylit areas. Only those finally selected are reported in table.

DAYLIT AREAS	STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
LIVING ROOM 1 Window 6.2 * 2.4m 1 Glazed Door 2.8 * 2.8 m	South and West windows, high-priced products. Colour rendering is important.	Modest size of windows. Glare risk from front view.	First exhibition area. Ask about plans, such as expected visit time.	Transition zone to the rest of the showroom, many customers are not interested in the product range and they will skip it.
HOME DECORATION 2 Windows 16 * 2.4m 1 Door 2.8 * 2.8 m	Fully glazed West and North façade in the area. HCL fixtures installed.	Highly exposed to direct solar radiation during peak times. Interior sun shading.	Low-priced and garden products, where daylight plays a major role.	Customers can be disturbed by excessive sunlight.

Located on the first floor, the Living Room (LR) (Figure 1) is the first department being crossed by customers, initially identified as an interesting place to ask clients about the time they plan to spend in their visit. The area presents a south-facing window and a glazed door oriented to the west, from which daylight penetrates during most of the daytime. Part of the electric lighting in the area is equipped with daylight harvesting. The living room area exhibits products where the quality of light and rendering of colours is relevant. Such products are sofas, armchairs and coffee tables. Compared to the products range in the store, those are usually the most expensive goods, so interested customers tend to stay longer to examine them in detail and compare the different textures and colours available.

Fig. 1: Living Room department: Picture and floor plan with suggested walking path.

The Home Decoration (HD) department (Figure 2) is located on the ground floor; it is the second to last area before entering the final self-serve collection area. The offered products are low-priced, consisting mainly of indoor plants, gardening and small decorative objects such as candles and vases. The area receives both daylight and electric light, the latter being provided by spot lamps and a number of HCL panes. The windows have a direct view to the street, and are almost full floor-to-ceiling height, with a sill of only 40 cm. The view from the north window is oriented to a playground and the west window provides a view over the parking lot.

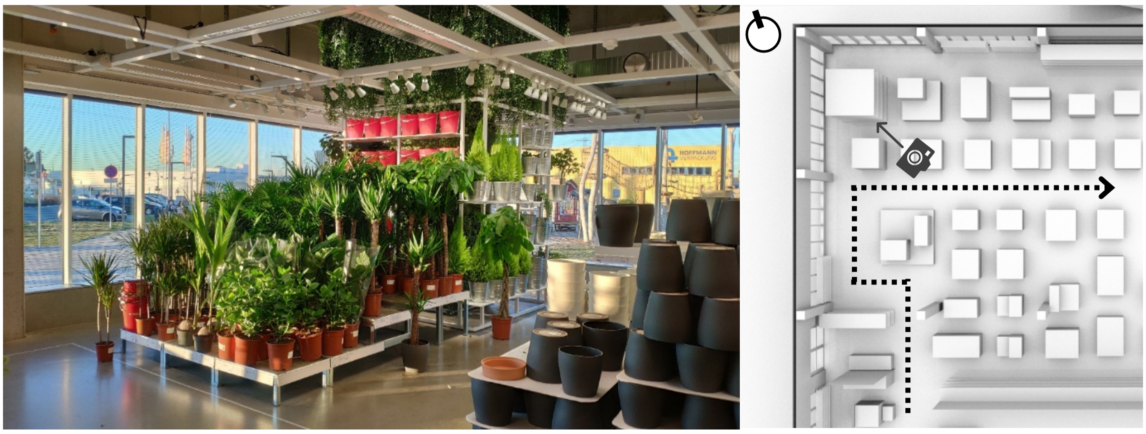

Fig. 2: Home Decoration department: Picture and floor plan with suggested walking path.

It is important to note that both areas have a suggested walking path which is drawn on the floor and predetermined. Customers are prompted to walk on that path in order to observe the whole product range; thus, it is interesting to evaluate the lighting conditions on this specific path, rather than on traditional grid of points, which are more suitable for traditional office settings.

2.2 Monitoring

2.2.1 Energy

The shop was not designed with a separate circuit for lighting; therefore, it is not possible to meter the electricity use for lighting only. As alternative, the comprehensive method to the standard EN15193 (CEN, 2017) was used. Input data were based on measured quantities, like actual occupancy profiles and dimming schedules. The energy for lighting systems in the two selected zones, LR and HD, was calculated through the characterization and quantification of the luminaires, via field verification of the luminaires, circuits and controls. The energy calculation workflow is summarized in Figure 3.

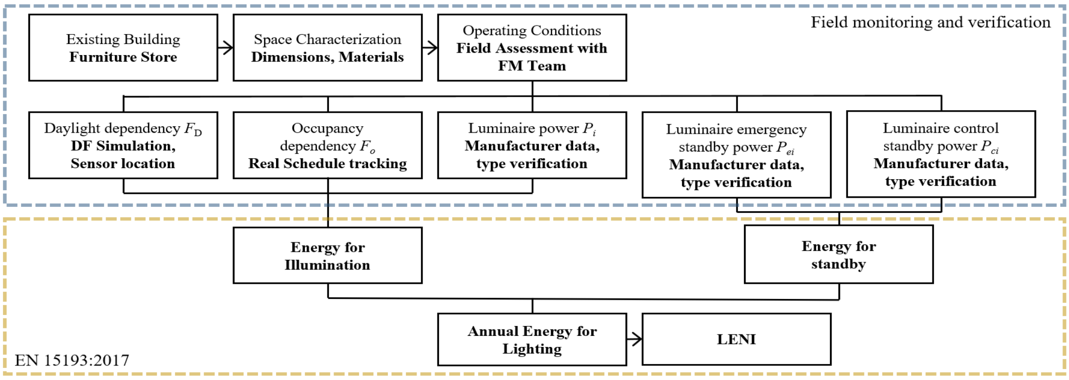

Fig. 3: Energy use for lighting calculation workflow.

In order to quantify the total installed power and calculate the energy used for the lighting and the standby of the different control systems, luminaires in the LR and HD area were identified and accounted for, as can be seen in Table 2. Few luminaires for general lighting (LED linear Grid), specifically 17 in the living room and 35 in the home decoration, were dimmed by an illuminance sensor. In order to obtain the real operating profile and the dimming schedule of those luminaires, two illuminance sensors were installed at each zone for four weeks. One sensor was placed under scheduled dimmable luminaires and the other, used as reference, under non-dimmable spotlights. The other luminaires, including the HCL Panels which are potentially dimmable, operated at a fixed luminous flux (Table 2).

Tab. 2: Number and specifications of luminaires. (Melanopic ratios for each luminaire measured on-site).

Type of fixture	LED Linear Grid	LED Spotlight	LED Spotlight	LED Projector	LED HCL Panel
Power [W]	17	10.4	37	25	54
Luminous efficacy [lm/W]	138	75	72	60	143
CCT [K]	4000	3500	3500	4000	2700 / 6500
Melanopic Ratio	0.78	0.62	0.66	0.76	0.45 / 1.05
Dimmable	Yes / DALI	No	No	No	Yes / DALI (Fixed to 80%)
Daylight Harvesting	Yes (Some zones)	No	No	No	No
Total units installed / (of which) with daylight harvesting					
Living Room Area	70 / 17	87 / 0	37 / 0	3 / 0	No
Home Decoration Area	76 / 35	39 / 0	54 / 0	4 / 0	24 / 0

2.2.2 Photometry

The photometric evaluation consisted of on-site point-in-time TEAs and few complementary daylight simulations based on measured data. An overview of the photometric evaluation is provided in Table 3.

Tab. 3: Summary of photometric assessments (M = "Measured", S = "Simulated", E = "Extrapolated").

Assessment		Type	Scope	Notes
Horizontal illuminance (outdoor)	M	Point	Overall evaluation of weather conditions	Two sensors for diffuse and global horizontal illuminance. Conditions logged continuously for five weeks.
Horizontal illuminance	M	Grid Path	Comparison with standard requirements	Measured daytime and night-time General lighting could not be switched off during day for DF assessment
Cylindrical illuminance	M	Path	Evaluation of illuminance at customer eye height	Measured morning, noon and evening. Average Result
Vertical illuminance	M	Path	Evaluation of circadian potential (at a later stage)	At four directions for each point
Spectral Power Distribution (SPD)	M	Path	Evaluation of circadian potential (at a later stage)	At four directions for each point
Reflectance of surfaces	M E	Image	Input for simulations	Measured with luminance meter and reflectance plate for main surfaces Extrapolated from photographs for exhibited products
Daylight Factor (DF)	S	Grid	Comparison with standard requirements	With and without furniture at height 0, 0.85 and 1.7 meters
Daylight Autonomy (DA)	S	Grid	Comparison with standard requirements	Without furniture
Annual direct sun hours	S	Grid	Evaluation of time with direct sun in the space	At view-height 1.70 m (grid cell of 0.25 x 0.25 meters).
View out	S	Grid	Comparison with surveys	As percentage at view-height 1.70 m for a vertical cone vison of 60° and horizontal field of 360°
Daylight Glare Probability (DGP)	S	Image	Comparison with surveys	Only for specific locations and critical view directions from Annual direct sun hours.

Grid-based and path-based TEAs in Table 3 represent assessments taken at points located either on an ideal square grid or on the walking path as described in §2.1.

The ideal grid is used as it is the standardized approach for photometric measurements of day- and electric lighting; the walking path is used as it is of particular interest for the evaluation of this case study. The distance between points in the grid is two meters and the size of the grid complies with the European Standards EN17307:2018 for daylighting (CEN/SIS, 2018) and EN12464-1:2011 for electric lighting (CEN, 2011). The path-based points had a maximum distance of 2 meters between each other and they were centred in respect to the path. The eye height was set up at 1.70 meters for all the points, since both customers and staff are expected to be standing in the space.

TEAs were carried out with professional and calibrated instruments. The simulations were run using Honeybee plug-in (Sadeghipour Roudsari, M, 2013) for Grasshopper - Rhinoceros (Robert McNeel and Associates, 2019) with Radiance (Ward Larson, G and Shakespeare, R., 1998) as simulation engine. Finally, for the reflectance of surfaces used in the simulation, the main (fixed) surfaces were measured with a professional spot luminance meter and a calibrated diffusive plate of known reflectance. For the reflectance of items being sold, which are changing constantly, photographs of the space were post-processed and the reflectances extrapolated from the surface colours. Although this does not guarantee very accurate absolute values of reflectance, the method was considered appropriate for a space with huge and constantly changing variety of surfaces.

Some simulations, like DF, were indispensable because of practical reasons. For example, DF could not be measured on site since a) there was not a single completely overcast sky day during the entire monitoring period and b) because of security reasons, it was impossible to access during closing hours, when the electric lighting was switched off.

In addition to the TEAs listed in Table 3, two indoor illuminance and temperature sensors with datalogging were placed first at the LR department for five weeks, and later on in the HD during 2 weeks. The logging from these sensors were used to cross-check some answers from customers and staff surveys.

2.2.3 Circadian potential

The circadian potential of the spaces was assessed based on the SPD measurements taken during daytime on the early afternoon of March, 2nd 2019, with partly cloudy sky, at standing view-height, for each of the points assigned to the main path for costumers, looking at four different directions, see Table 3. This point-in-time well represented an average daylit scenario for the shop. The SPDs were processed through the irradiance toolbox excel spreadsheet developed by Lucas et al. (2014). The ratio between the equivalent Melanopic and Photopic Lux (M/P) was calculated, and the following categories assigned: 1) M/P > 0.9 “Intense Blue, Alertness”, 2) 0.35 < M/P < 0.9 “Neutral, Neutral”, 3) M/P < 0.35 “Blue Depletion, Calming” (Solemma, 2018). As a reference, the daylight M/P ratio is set to 1.10 (International Well Building Institute, 2017)

2.2.4 Users perspective

In addition to the data obtained from the TEAs, different types of longitudinal OBEAs, namely closed and open-ended questionnaire surveys, were carried out for both customers and staff. The OBEAs were carried out in the two studied areas, and at the cash line area.

Customer surveys consisted of five-points rating scales with additional space for free comments. The surveys were accessible online through QR codes for a period of two months. The QR codes were located on walls signs and roll-ups placed at the entrance and exit of each analysed area. By scanning the QR code, the client had access to a web-based questionnaire, which was automatically submitted once the last question was answered. Date and time of submission were automatically recorded. The survey was anonymous, but the respondent could voluntarily decide to submit gender and age. The survey was per area and not per customer, meaning that there is no possibility to know if who replied to the survey in one area was the same costumer replying at the other area.

Surveys at the two studies areas included questions on the overall evaluation of the lighting in the space and the view out, as well as self-evaluated mood, willingness to buy, thermal comfort and alertness. The survey at the exit included questions on the perceived shopping experience, and comparison with other ordinary stores of the same branch that were previously visited by the customer.

The survey addressed to the staff consisted of open-ended questions. The questions were provided on a web-based questionnaire which was accessible through a link provided by e-mail. Also in this case the answers were anonymous, but the respondent was asked to provide her/his role (facility management, marketing, management or sales team). Employees were asked about lighting in the space, views, and the implications for their daily working experience, both in the studied areas and the overall store. Taking advantage that most of the staff had been working at the old store in Kaarst, which was provided with little daylight, employees were asked to compare between stores.

3. Results

3.1 Energy

The integration of daylighting and electric lighting by means of daylight harvesting leads led to energy savings. However, compared to light fully on, these savings were limited. Indeed, the energy use was reduced only by 1.1 and 0.6 kWh $m^{-2}y^{-1}$ depending on the area (Table 4), most probably because the dimmed fixture are already very efficient (138 lm W^{-1}) and they have a low wattage (17 W per unit) (Table 2). It is worth mentioning that the calculated LENI value is about half of the benchmark provided by EN15193:2007 (CEN, 2007).

Tab. 4: Energy use for lighting in the studied zones with Daylight integration and with no Daylight integration.

Studied Area	**PN** [Wm^{-2}]	**LENI** [kWh m^{-2} a] **Daylight integration**	**LENI** [kWh m^{-2} a] **No Daylight integration**	**LENI** [kWh m^{-2} a] **Energy Saving**	**LENI** [kWh m^{-2} a] **Benchmark** EN15193:2007
Living Room	7.8	40.3	41.4	1.1	78.1
Home Decoration	16.3	84	84.7	0.6	78.1

3.2 Photometry

In the living room area, the average illuminance for the grid assessment is virtually unchanged during daytime ($\bar{E}$ = 627 lux) and night-time ($\bar{E}$ = 600 lux), as the daylit area is small. However, daylighting improves the light uniformity in the space, raising from a uniformity ($U_0 = E_{min} / E_{average}$, see CIE 17-552) of 0.03 at night-time to 0.12 during daytime. On the contrary, daylighting in HD increases the average illuminance of the space by almost a third during daytime ($\bar{E}$ = 1456 lux) in respect to electric lighting only ($\bar{E}$ = 1011 lux), and it reduces the uniformity from 0.21 to 0.20.

The measured cylindrical illuminance during daytime was between 106 to 180 lux and 259 to 1329 lux for the living room and home decoration paths respectively. This is in line with the measurements of horizontal illuminance, which showed lower light levels and more uniformity for the living room.

In regards to DF, the average DF for the living room area at eye level is practically the same whether the furniture was modelled or not (DF of 0.5 and 0.6 respectively). In the home decoration area the simulated DF is 1.2 and 1.4 with and without shelves and expositors.

The DA was simulated with furniture only. The DA for 750 lux, i.e. target Illuminance selected from EN15193:2007 for the energy use calculations, during opening hours was of 21% in the home decoration department and of 15% in the living room, where the calculation was only limited to the zone with daylight harvesting. By reducing the benchmark to 300 lux, which is commonly used in office space, the DA becomes of 56% and 39% for living room and home decoration respectively.

In order to identify areas with higher glare risk, a preliminary analysis of area with direct sunlight was performed. Overlaying these results to the suggested walking path and considering the period of the year in which the surveys were conducted, two positions with potential glare risk were identified. Daily simulations run for February 15th with one-hour time step for these points show the highest DGP as in Figure 4.

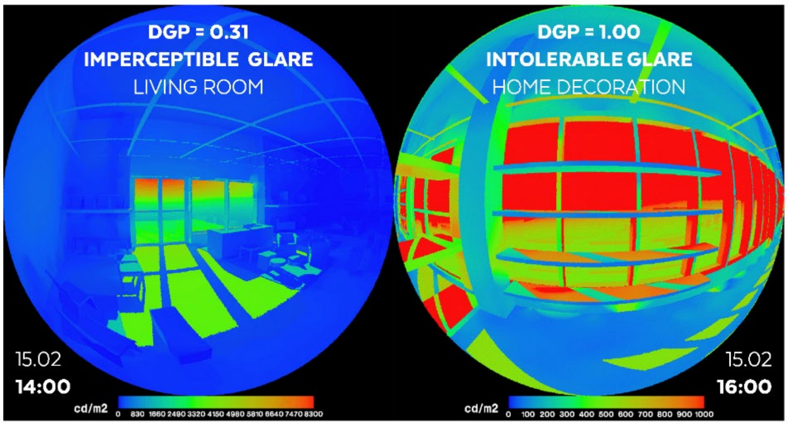

Fig. 4: Highest DGP recorded from the path during the survey period at the studied departments.

In the HD section, glare can be experienced only at 16:00. However, this setting does not seem to be a big concern, as the shelves in front of the windows are usually full of plants and these plants help to sift the sunrays, producing a pleasant greenish glow. This seems to be one of the reasons for the shelves being there. It seems that the path in both areas and the location of certain furniture has been studied with the aim of mitigating glare, which appears to be confirmed by the fact that the interior roll-up screens available in home decoration have hardly been used, as confirmed by the department's sales staff.

Concerning the view out for every department, a mesh of points was simulated, using cells of 25 by 25 centimeters at a height of 1.7 meters. At each point a vertical cone of vectors of 60 degrees (simulating human field of vision) and a 360-degree horizontal cone was generated, in other words, allowing people to look all around in a horizontal manner. The percentage of vectors that were not obstructed and crossed the glazed surface were quantified, then divided by the total number of vectors, resulting in the percentage of view outside at each point.

In order to quantify the floor area that has access to a quality view of the outdoors, an area with quality view was defined, as an area with a view factor of 20 degrees or greater as defined in the view factor classification 4 by the California Energy Commission (Heschong and California Energy Comission, 2003, pp. 47–50). The LR area obtained a 39% of the area having a good view-out, while the HD the percentage reached the 95% of the floor area. Consequently, it was observed that although in living room the glazed surface is 4 times smaller, the percentage of area with good view out is just a 41 percent lower.

3.3 Circadian potential

The M/P ratio was higher than 0.9 in most of the points of view where a window was within the visual field, even if the window were not close. Comparing the results of the two zones (Figure 5), it could be noticed that they were quite similar although the number and size of the windows are very different. In other words, even minimal daylight raised the M/P ratio. However, it is essential that the sight towards windows is unobstructed and electric lighting is minimized in such direction. Indeed, some areas of HD including electrically illuminated elements in the field of vision, had much lower M/P ratios despite being close to windows.

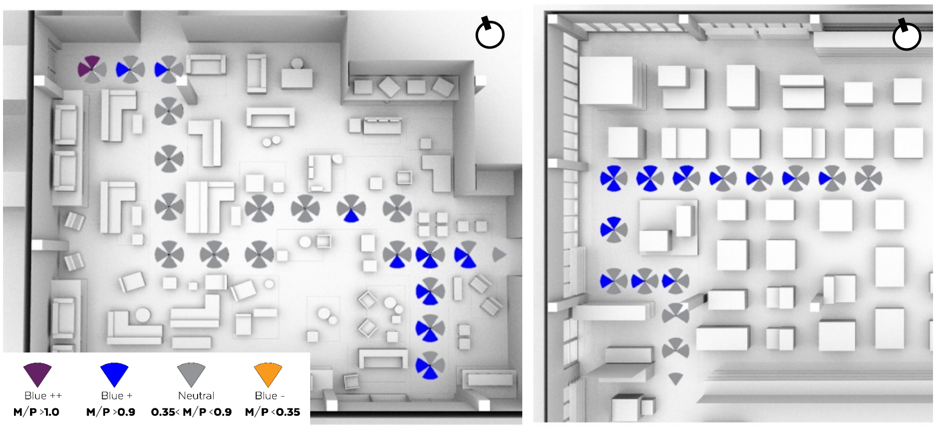

Fig. 5: M/P ratio along the path for the LR (Left) and HD (Right) departments.

3.4 User perspective

During the two months in which it was accessible, the surveys were responded by: 42 customers and 6 employees in the LR, and 48 customers and 6 employees in the HD. Additional 63 customers and 6 employees responded on the overall shopping/working experience at the cash line area.

Customers were asked to assess whether daylight was providing or not a good feeling. About 80% of the responses in the two areas were between “4-Agree” or “5-Totally agree”, showing that customers valued daylighting as something positive and something that improves the perceived atmosphere. In relation to the presence of daylight helping to a better orientation, the answers were slightly more positive than negative, but with a large dispersion. One reason could be that the term “orientation” is not of immediate understanding for customers.

Among respondents, 95% in the LR and 71% in HD agreed or totally agreed that daylight supports product presentation and the colours or material are shown better. Of the two customers who did not agree in the LR (5%), one commented that it was because "*The interesting products are not in the daylight*".

Interestingly, customers were more satisfied with the temperature in the HD (21.8 °C) than in the LR (21.3 °C), despite being almost identical. Considering current knowledge (Baker, 2000; Chinazzo et al, 2019), it may be speculated that the higher daylight penetration and greater visual connection with the outside in HD may affect thermal response.

When asked if they appreciated having views outside, in LR 82% of the clients said ‘Yes’, and one commented "*Nice to see sunrays entering and lighting the products*". This comment is well supported by Figure 6, where some customers are exposing products to daylight before deciding on the purchase, a circumstance which occurred several times during the site visits.

Fig. 6: Customers exposing products to daylight.

In HD the percentage was as high as 89% although some customers were more critical about the quality of the view, e.g. "*The view of the parking is not so great*" or "*The most beautiful view is obstructed*". This supported the rather positive outdoor view results that living room obtained in the simulations and suggests that even relatively small windows may positively impact on customers’ experience. It also reminds that the view quantity should be supported by proper view quality.

As a concluding comparison, and once the clients were already familiar with the spaces, they were asked to describe the amount of perceived light, as summarised in Figure 7. Regarding electric light, the profile of responses was very similar between the two zones, despite much higher measured illuminances in HD.

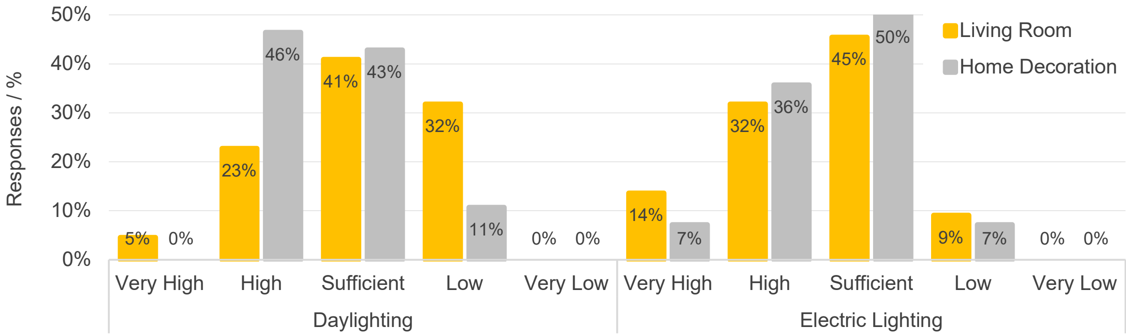

Fig. 7: How customers described the amount of light in the area.

Daylight appreciation differed much more, with most responses being “high” or “sufficient” at HD and rather spread in LR. Although in HD direct sun hours were abundant and the glare was potentially occurring, when asked about visual discomfort, there was no mention of discomfort due to daylight glare. There were indeed three customers who had complaints about the light emitted by spotlights. Since DGP has been developed for office space, it is possible that such metric cannot describe “discomfort” in a space were individuals perform different activities (shopping). On the contrary, many customers positively commented on the direct sun entering the space “*It's nice that the sun is coming in*”.

Customers were also asked whether they had previously visited another shop of the chain, and they were asked to compare some amenities with the shop in Kaarst (Figure 8).

Fig. 8: Breakdown of shopping experience aspects compared with other stores for new vs. returning customers in the store.

Most of the regular customer of the chain found that the shop in Kaarst – which differs from the others only for the daylight provision and its integration with electric lighting - provides a better atmosphere and shopping experience. In particular, the totality of responses indicates that lighting is better or equivalent to the other shops.

The survey to the employees was particularly interesting. The LR department, management team and sales staff claimed that having windows *"(it) makes you feel more positive and helps you to feel good*" and "*A lot of natural sunlight, one can see weather changes, natural light improves my mood*". When asking for drawbacks, the management team wondered about the sales "*Sales steering can be difficult due to distraction by daylight*". Other concerns regarded excessive contrast in clear days, where some zones are perceived darker; this claim links well with the uniformity issues found during the photometric assessments. Interestingly, some workers claimed that a drawback of daylight is actually the lack of daylight elsewhere: "*No natural light in the neighbor department which also belongs to my workspace*".

Moving to the HD department, positive aspects of the views out were added to the daylight provision. Shopkeepers also added the tunable HCL fixtures to the equation "*It is a beautiful and pleasant way to light up the department. On the one hand through the window, which let us see the day any time. On the other hand, also that the light color adjusts itself in the course of the day*". Management team added that the windows "*Create(s) a real greenhouse feeling that supports the range. Gives great views to the outdoor*", however, "*Due to long stretch of the windows, it is difficult to protect the plants and other items during sunny days*". Coworkers from the department also objected of overheating during summer, but tolerable glare. In addition, the management team believed that "*Good contribution towards a pleasant shopping experience and the overall quality impression of the store*", the marketing team pointed that the daylighting solution is "*Very pleasant for customers and employees. Very good feedback*", while shopkeepers added that "*Light makes customers happy. They don't feel so locked up*".

Finally, when asked to make a comparison with the previous store in Kaarst, which was a traditional one, the staff replied that "*There was barely any daylight in the old store*", "*In the old house I could never see any light during the day*", and "*No daylight, except for the lunch room and the checkout area*". They highlighted that this affected their daily work: "*Today, my workplace it's much more pleasant*", "*I'm happier now*" and "*One is more positive and feels less like at work*".

4. Discussion and conclusions

This paper described the case study of a furniture store integrating daylighting and electric lighting. The monitoring investigated energy use and lighting quality aspects by combining technical measurement and observations, as well as supplementary simulations.

The use of integrated lighting controls, such as daylight harvesting, could save some energy, although figures were lower than usually reported in literature. A reason could be the high efficiency of luminaires, which makes additional savings from controls rather marginal. Another reason is that only few luminaires in the studied object are actually daylight controlled. One way to increase savings is to provide the whole general lighting, including spotlights – which are the less efficient –, with daylight harvesting or daylight on-off. However, this should be carefully tested in respect to customers' experience.

The photometric assessment was used mostly to characterize lighting in the space. Despite being both provided with sidelight windows, the LR and HD showed pretty different daylight conditions, with the first having a lower maintened illuminance and higher contrast. This is clearly identified in the surveys, where high contrast is actually perceived negatively. The observations allowed to have a critical view on some of the objective photometric measures. For example, limited glare, which simulations showed to occurr, seems not to be a problem, rather an opportunity, given the type of activity that individuals are carrying out.

Windows, even of small size, may enhance the circadian potential of the space. Such potential in the store may be limited, since the exposure time is generally short, but it is important that this type of considerations are included in upcoming lighting integrated projects.

The comparison with the experience in other stores of the same chain show clearly that the introduction of the daylighting solution is valued by customers. The overall perception of the store improved. Among the positive remarks, the facts of observing objects under natural light, namely with high colour rendering, and having a (good) view to the outside seem to be the most important for customers.

The staff reported on a number of "soft" benefits of daylight, and their job satisfaction seems to be positevely impacted. They also could notice the electric solutions and they had positive remarks for the tunable HCL ligthing, which could provide a clear link with the time of the day. For that specific solution, this study could not provide major conclusions on the circadian potential of such luminaire due to the number of confounding variables, which is typical of an uncontrolled case study assessement. In addition, the staff remarked on some issues related to daylighting, such as the contrast generated with the smaller LR windows, and the overheating they experience during summer with the larger HD windows. However, despite these issues, staff members proposed adding more windows to boost views-out, and skylights to illuminate the core areas in the showroom. Overall, they valued daylighting as the most positive improvement in comparison to the older store.

In conclusions, integrating daylighting and electric lighting saved energy for lighting, but also provided a number of co-benefits in support of both the shopping experience and the working environment for the staff. In the case of furniture store, the use of aboundant daylight seems to be a valuable option for both customers and staff. However, there is little research, practical experience and, thus, guidance existing on how to correctly integrate daylight in the lighting design of furniture shops. Knowledge in this sense is hoped to prompt encorporation of daylighting even in the architecture of the retail sector.

5. Acknowledgments

The Swedish Energy Agency is acknowledged for the financial aid provided to support the activities in IEA SHC Task 61 / EBC Annex 77, of which the case study evaluation in this paper is part. The authors are grateful to the staff and the management of the shop in Kaarst for the support provided. Jonas Manuel Gremmelspacher is gratefully acknowledged for his assistance in translating the surveys into German.

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