Visual comfort and non-visual requirements for an ageing population

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Implementing daylight and electric light strategies in a care home in Brussels (Belgium) through a simulation-based approach.

A series of daylight and electric light strategies were proposed in a care home in Brussels (Belgium) to improve the visual comfort and circadian wellbeing of residents. The strategies were based on 3D simulations evaluating the quality and quantity of luminous exposures over time in several residents' living spaces.

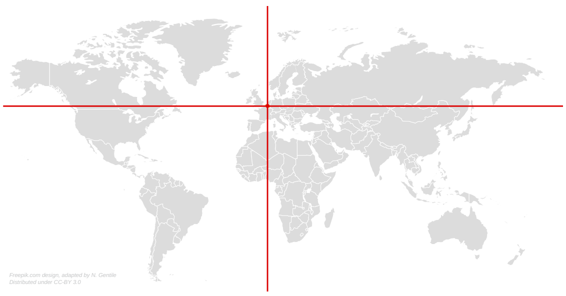
Figure 1. Stephenson Garden, Brussel.

The project

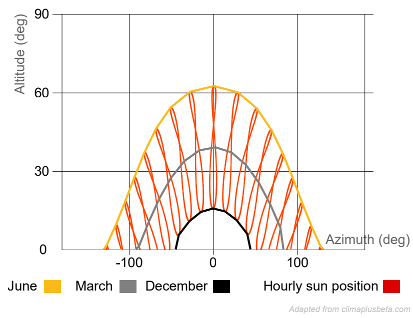
The Stephenson Garden (Fig. 1) is a 6-storey warehouse in Brussels that, in 2015, was refurbished into a care home. The renovation project – lead by the care home director, a former interior designer having worked for almost 20 years as nursing home manager – focused on conceiving spaces that could provide to the residents luminous continuity throughout their daily activities (Fig. 2). To this aim, several common spaces, open to daylight and external views, were arranged alongside patients' bedrooms at each floor (Fig. 3). The ground floor presents a different spatial organisation with fewer sleeping rooms, but two dining rooms (one in Fig. 4), a visit room and a living space. All spaces have access to daylight complemented by LED luminaires.

Monitoring

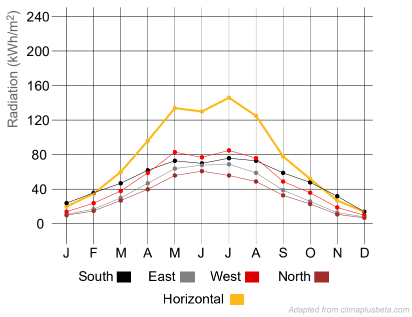
A detailed monitoring plan had been set up to take place in March 2020. Unfortunately, due to the SARS-CoV-2 pandemic, which inhibited access to all care homes in Belgium, the research strategy had to be adjusted, relying on computer simulations for the evaluation of visual and non-visual luminous exposures, and for the estimation of the energy performance of specific spaces within the building. The recently-released Climate Studio tool, alongside the DIVA-for-Rhino plugin, were used to perform climate-



Location: Brussels, Belgium
50.87°, 4.37°



Sun path for
Brussels, Belgium



Global horizontal and vertical radiation for
Brussels, Belgium

IEA SHC Task 61 Subtask D

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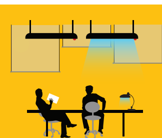

Figure 2. Rooms. Top: South-West oriented Bedroom, 2nd floor. Bottom: North-West oriented Dining Room (patio), Ground floor.

Figure 3. Bedroom in the Stephenson Garden.

based daylight simulations and to calculate the energy use. A circadian optimization of lighting calculation was done via the software tool ALFA.

Starting from the existing conditions (baseline), several scenarios aiming at providing access to the proper amount and quality of light were tested, of which some are shown here. The scenarios include the installation of complementary luminaires, adjustment of daily schedule or modification of furniture arrangement.

Energy

The energy performance compares the existing baseline situation (artificial lighting switched on based on occupants' presence, with no dimming) to a proposed improved scenario based on daylight availability, as well as visual and non-visual requirements.

The baseline scenario considered that, regardless of season or sky condition, between 07:00 and 23:00 electric lights are switched on whenever the rooms are occupied.

The proposed improved scenario dimmed electric lighting considering both visual (workplane photopic illuminance) and non-visual requirements (melanopic vertical illuminance). These required the installation of additional luminaires in the bedrooms and dining rooms. The evaluation was done for the 21st of June and 21st December, under overcast and clear skies.

Simulations were first run with daylight as the only light source. When electric lighting was needed, simulations were first run only with ceiling lamps. Finally, if daylight and the ceiling lamps did not provide sufficient photopic and melanopic illuminance, the additional luminaires were

Figure 4. Dining Room in the Stephenson Garden.

switched on. Table 1 shows that the proposed scenario allows a reduction of energy use in the South-West bedroom. For the dining room, energy consumptions associated with improved visual and non-visual luminous exposures are, however, mostly similar between the two situations. This was expected considering that the proposed scenario added 10 wall-mounted luminaires in order to respond to visual and non-visual requirements. Nevertheless, it must be considered that the simulations were run for the most disadvantageous location in the dining room in terms of orientation and visual and non-visual exposure. If other strategies were implemented, such as a change in the arrangement of the furniture, the adaptation of the schedules, and/or an individual control for each luminaire, the different thresholds could be more easily reached, reducing the need for electric lighting and its associated energy use.

Photometry

Figure 5 presents Spatial Daylight Autonomy (sDA) for the 300 lux threshold, Daylight Factor (DF), and Workplane Illuminance (provided by electric lighting only) for the bedroom and the dining room in the baseline scenario. The mean sDA for the bedroom is 18% and no place in the room achieves a value higher than 50%. A similar result was obtained for the North-West dining room, for which the mean sDA was around 5%. Regarding DF, the mean values for the bedroom and dining room are 2.1 % and 0.9%, respectively. The work plane illuminance levels reach the desired thresholds only at some specific points for the bedroom.

	June clear	June overcast	December clear	December overcast
Bedroom	kWh/m^2/day	kWh/m^2/day	kWh/m^2/day	kWh/m^2/day
Before	0.016	0.016	0.016	0.016
After	0.006	0.006	0.015	0.015
Dining Room	kWh/m^2/day	kWh/m^2/day	kWh/m^2/day	kWh/m^2/day
Before	0.021	0.021	0.021	0.021
After	0.018	0.024	0.022	0.022

Table 1. Daily energy use under baseline (before) and proposed (after) scenarios

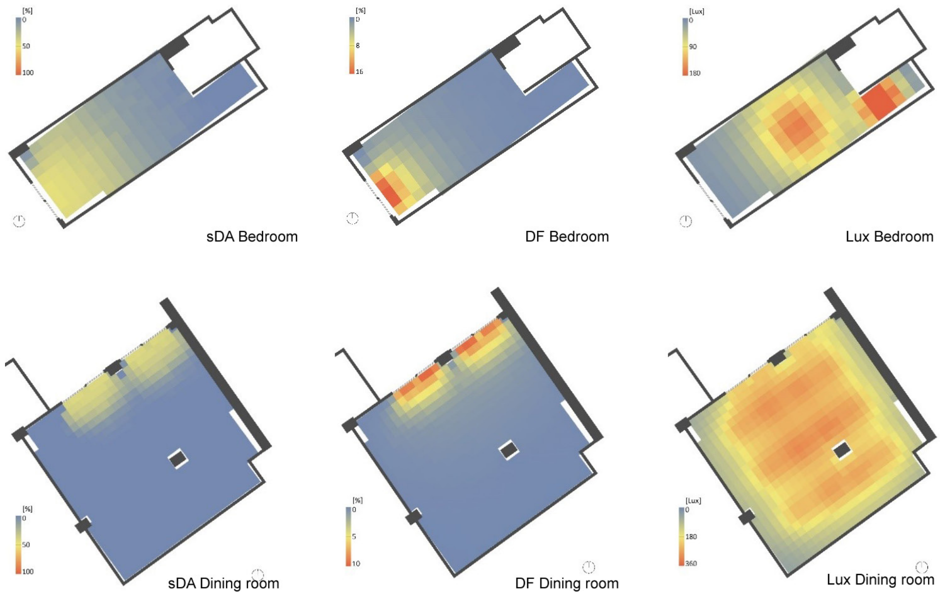

Figure 5. Spatial Daylight Autonomy (sDA), Daylight Factor (DF) and Workplane Illuminance provided by electric lighting for the monitored rooms. Top: bedroom. Bottom: dining room.

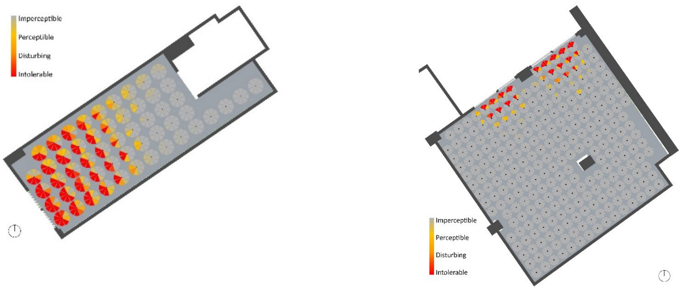

Figure 6. Spatial Glare Distribution for the bedroom (left) and the dining room (right)

In terms of annual spatial distribution of discomfort glare probability, near the window and facing outside the probability of disturbing glare is extremely high (Fig. 6). This would require the implementation of curtains, which could lead to an increase of electric lighting use. In the dining room, the risk of glare is lower and could simply be addressed by having tables located at a distance higher than 1.5 m from the windows.

Circadian potential

ALFA allowed to evaluate the circadian potential of various spaces through the estimation of the melanopic illuminance (equivalent melanopic lux, EML), and the M/P ratio. For all situations analysed, the Circadian Stimulus (CS) index was also calculated. The results obtained for these three metrics were compared to the thresholds defined by the current literature. However, since light transmission in the retina decreases with age, and phenomena such as the yellowing of the lens can further impair the circadian stimulation for the elderly, existing thresholds had to be adjusted.

The melanopic threshold at 250 EML for a person of 85 years of age was set via the SpeKtro tool by EPFL. Concerning the M/P ratio, it was considered that, when its value is above 0.9, the light source can have an alerting effect (during the day) or foster melatonin suppression (at night). Conversely, a M/P ratio lower than 0.35 does not inhibit melatonin secretion. On these bases, the chosen thresholds aimed at maintaining a M/P ratio above 0.9 until 11:00 and under 0.35 from 17:00. For the CS, between 07:00 and 11:00, a value higher than at least 0.3 was sought, while after 19:00, the CS must not exceed 0.1.

The analysis was based on the use of three "personas", that is, personal representations of occupants' activities that can exemplify different lighting requirements and conditions experienced through a series of typical days. The simulations recorded the luminous exposures of these personas based on a schedule of daily activities provided by the care home, and were ran every 3 hours, in both winter and summer, under clear and overcast sky conditions.

The two examples shown in this section are for the 21st of December with an overcast sky condition, to stress out the need for integration of daylight and electric lighting. The bedroom is originally electrically lit by a LED ceiling lamp and a LED spotlight in the entrance. The simulations present the luminous exposures for a persona, at the times of breakfast and dinner. The dining room is electrically lit by 12 LED ceiling lamps. Since some residents also attend afternoon activities in the same room, simulations were run at 16:00 and 19:00 in that space. In this case, the simulation was done for two personas, one located near the windows and facing outside, the other looking in the opposite direction and placed at the back of the room (see the results presented in Table 2).

An initial analysis of the simulation results led to detect a lack of potential circadian stimulation in the morning (07:00) due to low melanopic illuminance in the resident's rooms, see Table 2. Thus, it was proposed to use a desk lamp with two switches triggering, respectively, a blue-shifted or a red-shifted LED light. By doing so, in the morning, the residents would have blue-shifted light to entrain their circadian rhythm, while a red-shifted light in the evening could ensure visual comfort without inhibiting melatonin secretion. Based on this simple strategy, the required thresholds could be achieved in the morning: 772 EML, a CS of 0.51, and a M/P ratio of 1. In the evening, this strategy led to detect the following values: 8 EML, a CS of 0.02, and a M/P ratio of 0.02. Although the use of the red-shifted desk lamp, combined with the presence of two ceiling lamps, did not alter substantially the quantity and quality of light towards the circadian well-being of residents, it resulted in an increase of the workplane illuminance values from 11 lux (i.e., with two ceiling lamps) to 307 lux.

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	Before				After			
Bedroom	**M/P**	**EML**	**CS**	**Plane lx**	**M/P**	**EML**	**CS**	**Plane lx**
07:00	0.75	12	0.02	12	1.00	772	0.51	357
19:00	0.71	5	0.01	11	0.02	8	0.02	307
Dining Room	**M/P**	**EML**	**CS**	**Plane lx**	**M/P**	**EML**	**CS**	**Plane lx**
16:00	0.95			306	0.68			975
	0.82			232	0.23			768
19:00	0.85	120	0.23	247	0.01	2	0.01	456
	0.79	39	0.08	224	0.01	4	0.01	459

- Blue-enriched
- Neutral
- Blue-depleted
- Do not meet threshold
- Meet the threshold

Table 2. Results of the ALFA Simulations of the 21st of December, with an overcast sky

In the dining room, the simulation detected the risk of excessive melanopic stimulation in summer during the evening hours. At the most exposed seating positions, both the EML and CS values were substantially above the required thresholds: 120 EML and a CS of 0.23. Moreover, the workplane illuminance was not sufficient across the entire space. The challenge, therefore, consisted in lowering the values of melanopic illuminance while preserving sufficient horizontal light distribution. Therefore, a dynamic electric lighting system was proposed to provide abundant light during the afternoon and a dimmed ambiance for the evening. This was done through the implementation of 12 ceiling lamps with a M/P ratio of 1, and 10 wall-mounted lights with a 0.01 M/P ratio. Both systems were set to be switched on in the afternoon, while only the wall-mounted lights were active in the evening, providing sufficient workplane illuminance and a sufficiently low melanopic exposure (2 and 4 EML) and circadian stimulation (0.01 for both personas included in the simulations).

Further strategies to respond to occupants' visual and non-visual needs consisted in the review of the residents' schedule of activities (so as to choose the rooms occupied throughout the day based on the effective daylight availability) and adjustments to the arrangement of the furniture (to guarantee proper exposure, or protection, from light sources). In some cases, compromises would need to be made between responding to requirements for visual comfort and circadian entrainment or rather supporting the psychological desires of residents to have direct access to an external view.

User perspective

The strategies proposed were discussed with the health care personnel (n = 7), to also gain insights on the habits of the residents, and with the director of the Stephenson Garden. The responses were generally supportive of the strategies proposed. It was, in fact, emphasised that most residents spend a relevant amount of time in their bedroom, making it essential to provide them with suitable lighting conditions by ensuring an efficient work plane illuminance along with appropriate EML and CS values throughout the day. The proposition of dynamic lighting settings via the use of blue-shifted lighting in the morning, and red-shifted lighting in the evening, could provide substantial benefits, especially since residents tend to often keep their curtains closed. However, the director stressed that it would be challenging for the health care personnel to implement the required lighting strategy at the appropriate timing, therefore suggesting the use of an automated system that could provide the residents with the adequate light exposure based on season and time of day.

Lessons learned

The analysis showed that with relatively simple measures – a careful integration of daylight and electric lighting strategies, the proper selection of lighting systems, schedule of daily activities, and spatial organisation – a care home can offer to its elderly residents proper lighting conditions to enhance their visual comfort, support their circadian well-being, and guarantee an effective energy performance for its lighting needs.

Logically, some limitations have to be acknowledged before the results of this analysis can be transferred to other contexts. In fact, the results were uniquely obtained through computer simulations without data having been validated by real measurements (e.g., to verify the effective daily 'lighting diet' of residents or the extent of any circadian disruption symptoms as revealed by biological markers). Also, it must be considered that – to guarantee a manageable volume of data to be analysed – the age of the residents was considered as fixed to 85 years. People of different age could have different lighting requirements. A further step of analysis would therefore consist in defining appropriate methods to adapt the necessary thresholds to the needs and subjective conditions of building users.

Further information

D. Carmon., 2020. *Lighting for an Ageing population*. Master Thesis at UC Louvain, Faculty of Architecture, Architectural Engineering and Urbanism, *not published*

D. Carmon and S. Altomonte, 2021. *Lighting for circadian well-being: a new simulation-based approach for the visual and non-visual lighting design of a nursing home*. Paper submitted to BS2021

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