Low-cost manually activated shades and tunable lighting in historical building

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Motorized roller blinds and dimmable-tunable LED to improve comfort and save energy at Abazia San Lorenzo ad Septimum.

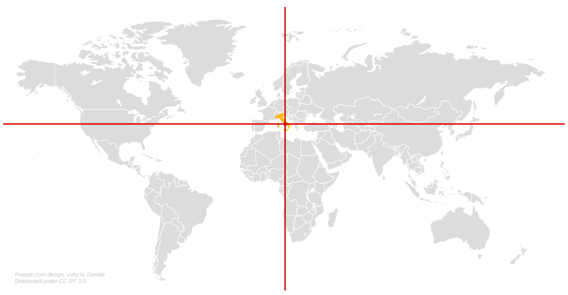
A low-cost manually controlled system, consisting of two motorised roller blinds and six dimmable and tunable led-based luminaires, was installed in a "Living lab" at the Abazia San Lorenzo ad Septimum to investigate the integration of artificial lighting system with shading systems and to guarantee user satisfaction, while energy savings were achieved by simply training the users.

The project

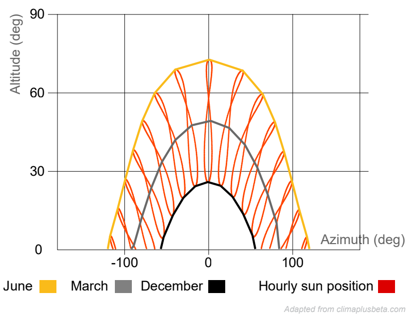
In this study, users' behaviour and the energy use for artificial lighting were evaluated in a real-world office (living lab) while performing ordinary working activities. The office is a private one, which is located on the first floor of the Abbey San Lorenzo ad Septimum (Fig. 1). The only window of the office is placed on the outer side external wall with an orientation of 15° South-South West. The window has a total surface of about 3.70 m^2, a ratio glass area/total window area equal to 0.38. For this research, commercially available low-cost manually controlled shading and lighting systems were installed in the living lab. Since the building is listed, the shading and lighting systems were installed in a non-invasive way, without intervention on the masonry. The scope was to simulate a potential real life retrofit of

Figure 1. External view of the Abazia San Lorenzo ad Septimum façade.

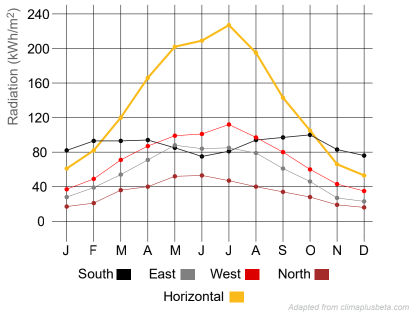
existing listed buildings. The shading system consists of two motorised roller blinds manufactured by IKEA, with different visual transmission values: one is semi-transparent, while the other is a "blackout" one. The lighting system consists of six wireless LED-based luminaires manufactured by IKEA (29 W, about 76 lm/W). The luminaires are provided with seven-step dimming and three-step tunable Correlated Colour Temperature (CCT) (2200 K – 2700 K – 4000 K). Both roller blinds and smart luminaires are controlled with remote control. Fig. 2 displays the internal view of the living lab, the shading systems, the lighting system and the position occupied by the user.



Location: Aversa, Italy
40°59' N, 14°11' E



Sun path for
Naples, Italy



Global horizontal and vertical radiation for
Naples, Italy

IEA SHC Task 61 Subtask D

Monitored by **Michelangelo Scorpio, Giovanni Ciampi, Niko Gentile, Yorgos Spanodimitriou, Roberta Laffi, Sergio Sibilio**
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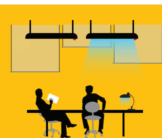

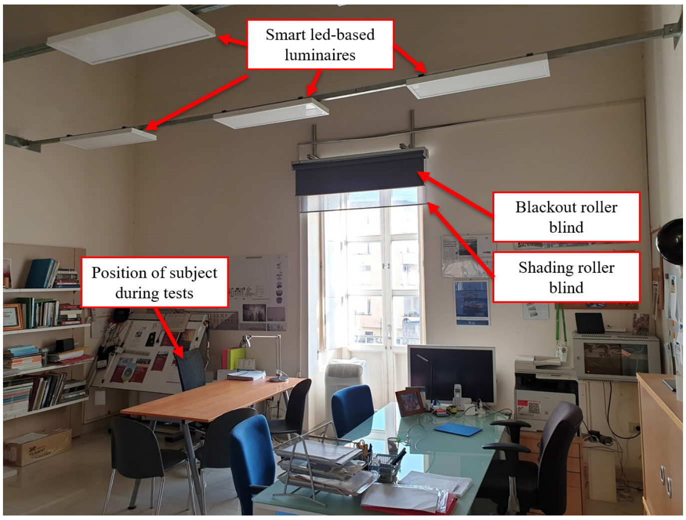

Figure 2. Inside view of the office.

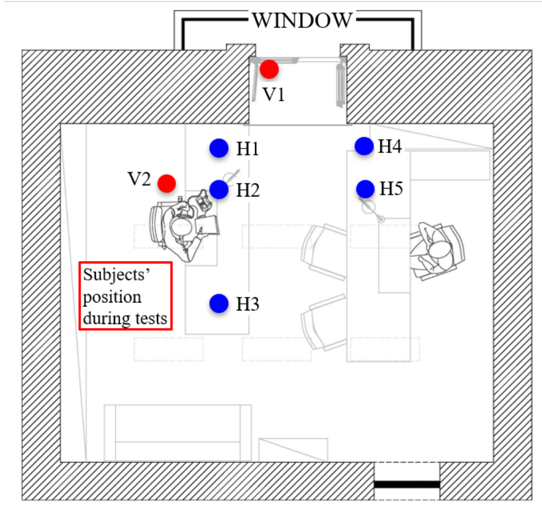

Figure 3. Office layout with the position of indoor sensors.

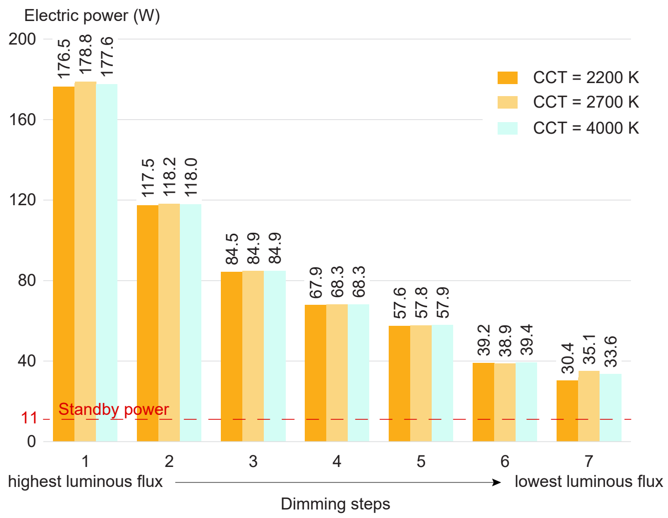

Figure 4. Electric power required by the lighting system for the different dimming and tuning steps, including standby.

Monitoring

Although two working stations were set up, the office was used only by one person during the tests. During the monitoring period, each subject performed ordinary office tasks, mainly focused on PC typing and reading, for two weeks. The subject was able to adjust the position of the two motorised roller blinds and the six smart luminaires through wireless devices, according to their needs, while sitting at the desk. Before the monitoring period, the subjects were trained on the use of the system and informed about the importance of good day-/lighting. During the two weeks experiments, the subjects received also email reminders about the importance of using natural light and combine it with the "right" type and amount of artificial lighting, if needed. Simultaneously, physical quantities were measured to evaluate the boundary conditions and user interaction with the systems. The monitoring follows the recommendations of the IEA Task 61 Monitoring Protocol.

Energy

The dimming level of the luminaires was evaluated by measuring the power required by the whole lighting system, while the CCT was assessed using an RGB sensor placed close to one of the luminaires. The electric power needed for the standby mode was also monitored. Fig. 4 displays the electric power required by the lighting system in the standby mode as well as upon varying dimming step and CCT values. Since each roller blind was equipped with a battery (no connections to the electric grid are required), their electrical use was neglected.

Photometry

The external daylight availability was evaluated by measuring: external horizontal global illuminance and external vertical global illuminance on the window's external side. Photometric measurements were performed to evaluate the reflectance and colour values of the internal surfaces, the indoor light distribution and outdoor daylight availability. The indoor light distribution was acquired by using five lux-meters placed in a horizontal position at the work plane level, 0.73 m from the floor, one lux-meter was placed in a vertical position just behind the glazing and one lux-meter was placed in a vertical position at 1.22 m from the floor to simulate the eye of a user seated at the desk (Fig. 3). Both roller blinds' positions were evaluated by measuring the distance between the bottom of each roller blind and the floor; the distances were measured using ultrasonic sensors installed on each roller blind. Finally, the subjects' visual connection with the outside was evaluated through the view out from the desk (Fig. 5). With a horizontal sight angle of about 15°, the view can be rated as "minimum", even if two layers are visible from the given position.

Fig. 6 reports the comparison between the outdoor vertical illuminance on the external surface of the window, the indoor vertical illuminance just behind the glazing, the illuminance on the task area, the vertical illuminance at eye level, the electric energy used by luminaires as well as the closing degree of both shading and blackout roller blind, for two subjects, while the regions in light green indicate the occupancy of the office. Measurements were performed in November 2020 and February 2021 and suggest a good daylight availability in the office, even in the winter, and

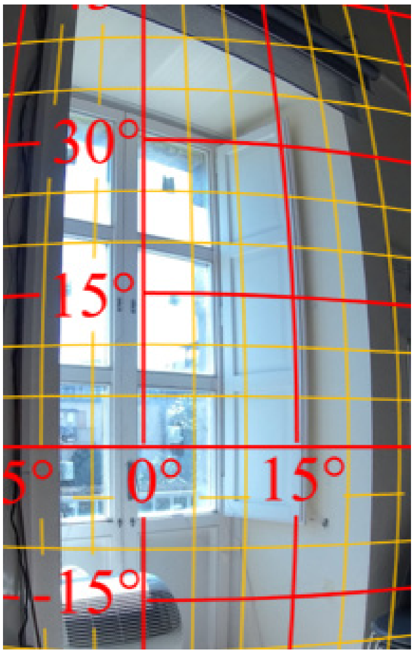

Figure 5. View out from the point of view of the subject seated at the desk.

that the user generally preferred to allow as much daylight as possible, even when the work plane is hit by direct sun radiation (graph on the right in Fig. 6). The figures underline that the blackout roller blind closing degree strongly influences artificial lighting system use, even with clear sky conditions. When the blackout blind is completely closed, the user considers the daylight amount in the room as not enough and then turns on the artificial lighting. Nevertheless, with better adjustment of the blackout blind position, the user may avoid glare - if occurring - and rely on daylighting only. Interestingly enough, when the shading is rolled up again, the artifical lighting is switched off. This contrasts with most of literature in the topic and it is arguably linked either to the training of the user or to the availability of both remote controls for shading and lighting at the desk. Finally, changes in dimming and CCT were very limited.

Circadian potential

During the day, daylight in the test room is mixed with artificial lighting following the individual choices of the occupant. To evaluate the light circadian potential at the work space, spectral power distribution measurements were taken at eye level (1.2 m) for artificial lighting only (varying CCT and dimming step) and for daylight only, with overcast sky. The SPDs were imported to the Lucas' toolbox and CIE S 026 alpha-opic toolbox, using a 1 nm resolution. Then, the photopic illuminance, the melanopic illuminance, the Equivalent Daylight Illuminance (EDI), and melanopic over photopic illuminance ratio (M/P) were calculated (Table 1). Regarding the EDI values greater than 250 lux would be desirable during the day (Brown et al, 2020). M/P ratios values higher than 0.9 indicate a blue-enriched lighting, supposedly prompting alertness. For example, the WELL standard adopts a fixed M/P = 1.1 for daylight as illuminant. Interestingly enough, none of the current artificial lighting scenario is able to achieve EDI > 250 lux, despite being dimensioned for the delivering the standard 500 lux (photopic) on the desk. For this location, instead, daylight can reach the threshold even during an overcast sky day (Table 1). Therefore, if the design aims at eliciting circadian response, either artificial lighting should be overdimensioned in respect to today standard - with obvious rebounds on the energy use - or more daylight should be allowed in the space. The latter appears to be a smarter solution for both the environment and the user.

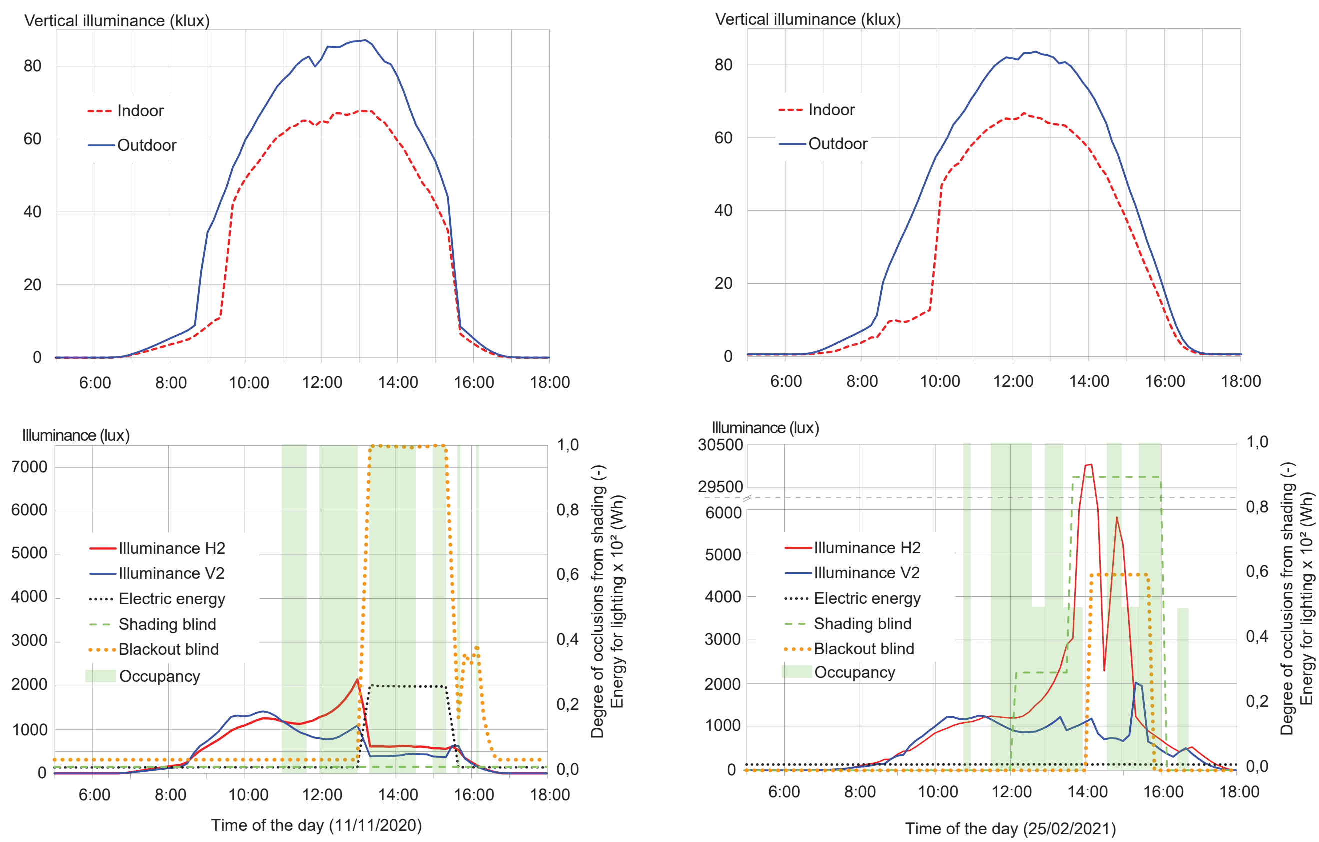

Figure 6. Indoor and outdoor physical quantities acquired during a day with clear sky conditions for two subjects.

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Table 1. Photopic and melanopic illuminance, EDI and M/P ratio under different daylighting and artificial lighting conditions.

Artificial lighting CCT = 2200 K							
Dimming step	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Photopic (lx)	300	180	109	66	40	24	15
Melanopic (lx)	89	53	32	20	12	7	5
EDI (lx)	80	48	29	18	11	7	4
M/P ratio	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Artificial lighting CCT = 2700 K							
Dimming step	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Photopic (lx)	323	195	117	71	43	26	16
Melanopic (lx)	132	79	47	29	18	11	7
EDI (lx)	119	72	43	26	16	10	6
M/P ratio	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Artificial lighting CCT = 4000 K							
Dimming step	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Photopic (lx)	351	212	128	78	47	29	18
Melanopic (lx)	210	126	76	46	28	17	11
EDI (lx)	190	114	69	42	25	15	10
M/P ratio	0.6	0.6	0.6	0.6	0.6	0.6	0.6

Daylight overcast sky									
Time (09:00-17:00)	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*
Photopic (lx)	180	165	240	141	105	121	171	413	325
Melanopic (lx)	168	154	225	133	98	112	160	382	304
EDI (lx)	152	139	204	121	89	102	145	346	276
M/P ratio	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

User perspective

During the two weeks, the participants used rarely the artificial lighting. In contrast, they used quite extensively the shading devices. Because of the room orientation, direct sunlight resulted in glare or reflections during the early afternoon. All the participants decided to lower the shading at this time, although some opted for the blackout shading, others for the semi-transparent. In most cases, the artificial lighting was turned on right after, at different levels of dimming and typically with neutral CCT. The CCT itself was rarely adjusted and, if it was, that was not done in relation to the time of the day, namely cold light in the morning, warm in the afternoon, but according to individual preferences only. There was also little corelation between the chosen CCT and dimming level. The participants were exceptionally satisfied with the level of control they had on both day- and artificial lighting, and with the option of having remote controls available right next to the workspace. A participant was sad when the two weeks were over and wanted to stay longer in the test room. They considered that the system could accommodate all their needs. Extreme behaviours were observed, with some partipants preferring to use artificial lighting, and others making use of daylighting as much as possible. In any of the case, the participants had highly conservative energy behaviors. For example, the "artificial lighting" participants made a greater use of the dimming functionalities, while the "daylighting" participants simply did not use artificial lighting. In follow-up interviews, the participants claimed that the room was very well daylit and that they did not feel the urge of using additional artificial lighting. But they also claimed that the training helped them in thinking before acting on lighting. Opinions on the usefulness of email reminders were more spread, with some users being annoyed by them. All in all, it seems that a very simple integrated manual system, provided with extensive options (shading, dimming, CCT) and with available controls, can satisfy the most and allow interesting energy savings. In respect to the latter, a proper training and information of the user seems to be extremely useful.

"I told them I was not going to leave that office after the test!"

Lessons learned

The results are in line with the literature on the topic. Subjects show a general preference towards daylighting, limited use of artificial lighting, a limited interaction with the systems during working hours, and some minor occurrences of energy wasteful behavior. Results also generally suggest that artificial lighting is limitedly used when a good daylighting design is set up, which makes the energy use for standby not of secondary importance in private offices. Generally, accessible manual controls can help the users maintain visual comfort in the office. Users' training could guarantee quasi-optimal use patterns of shading devices and artificial lighting, possibly comparable to those of automatic systems. Results also underline that when the blackout roller blind is completely closed, the users preferred to switch on the artificial light system even for computer-based tasks. This calls for a deeper investigation of integrated design, with more specific recommendations based on user preferences and tasks. Results underline that the tested system is eligible for both to be installed in historical buildings as well as improve energy saving and visual comfort.

Further information

G. Ciampi, A. Rosato, M. Scorpio, S. Sibilio, *Daylighting contribution for energy saving in a historical building*, Energy Procedia. 78 (2015) 1257–1262. DOI:10.1016/j.egypro.2015.11.270

M. Scorpio, G. Ciampi, A. Rosato, L. Maffei, M. Masullo, M. Almeida, S. Sibilio, Electric-driven windows for historical buildings retrofit: Energy and visual sensitivity analysis for different control logics, Journal of Building Engineering 31 (2020) 101398. DOI: 10.1016/j.jobe.2020.101398

About the EDI thresholds: Brown, T., Brainard, G., Cajochen, C., Czeisler, C., Hanifin, J., Lockley, S., ... & Wright Jr, K. (2020). *Recommendations for healthy daytime, evening, and night-time indoor light exposure*. Preprint, not peer-reviewed.

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