NAVITAS – A Testbed for Integrated Daylighting and Electric Lighting Aspects

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

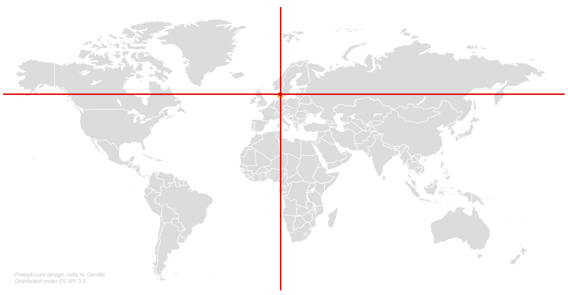
Largest low-energy building in Denmark provides good daylighting and allows for a detailed study of integrated electric lighting and solar shading

A study of integrated lighting at a research and education centre reveals that a highly energy-efficient building could be further improved through relatively simple measures. Such measures include shades that automatically return to a fully open state at the end of a day, a manual on-switch for electric lighting and better light sensor positions.

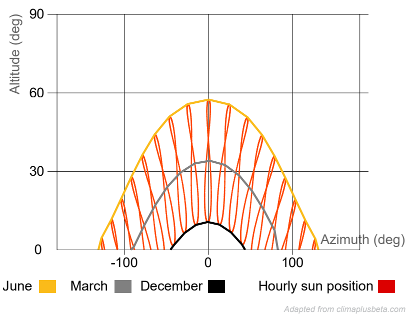
Figure 1. Navitas Building at Aarhus harbour front viewed from South.

The project

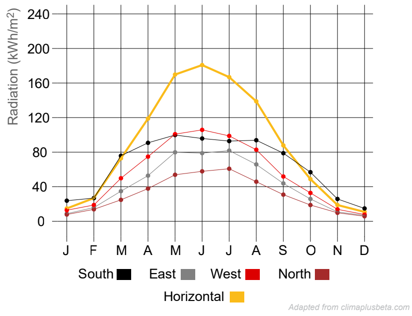
Navitas (Fig. 1) is a centre for education, research and innovation addressing climate, environment and energy at the harbour front of the City of Aarhus housing up to 3,000 students, educators, researchers and innovators on a floor area of 38,000 m². Navitas was built between 2011 and 2014 as a joint venture between Aarhus University, INCUBA Science Park, and Aarhus School of Marine and Technical Engineering at a cost of ca. € 95 Million. The final design was chosen through a competition requiring a turnkey contract with integrated designer and contractor teams. The chosen design also had the most appealing daylighting. All spaces used for extended periods have daylight access through the façade or interior courtyards/ atria (see also Fig. 4). The building is Denmark's largest low-energy commercial building and meets the stringent "Energy Class 1" requirements of the 2015 Building Regulations. Simulations could demonstrate that the building's energy use would be less than 50% of that needed by a standard commercial building. This was achieved through integrated energy design during the planning phase, a highly insulated building façade with triple-pane windows (t_{vis} = 53%), daylight-responsive electric lighting control with occupancy detection, 5,500 m² of photovoltaic panels on its roof, and cooling of ventilation air with water from the harbour. An intelligent building management system (BMS) permanently monitors indoor climate and lighting and adjusts values as needed. The lighting system (Figs. 2 and 3) uses T5 fluorescent luminaires (4,000 K) aimed at an illuminance of 300 lux on the work plane in offices, meeting rooms and classrooms and additional manually-operated desk luminaires to



Location: Aarhus, Denmark
56.16°N, 10.22°E



Sun path for
Aarhus, Denmark
(56.16°N, 10.22°E)



Global horizontal and vertical radiation for
Aarhus, Denmark
(56.16°N, 10.22°E)

IEA SHC Task 61 Subtask D

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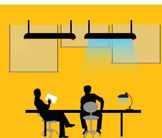

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Figure 2. Lighting and solar control in typical office space (04.103) at Navitas.

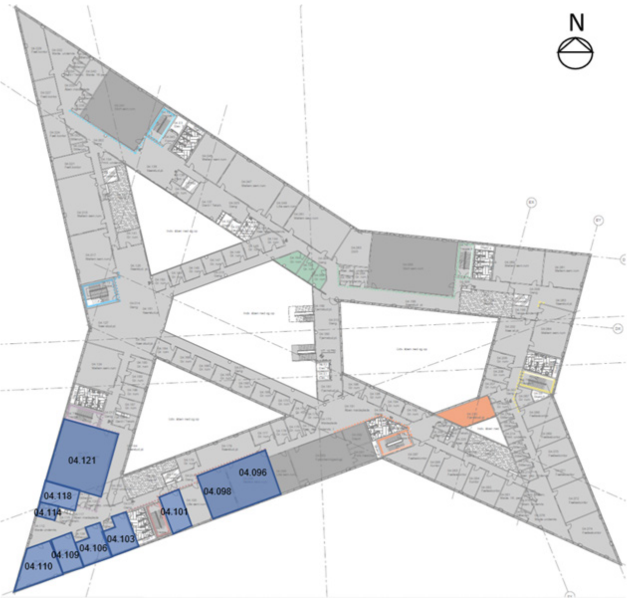

Figure 4. Fourth floor at Navitas with monitored spaces (blue).

reach 500 lux where required. Two luminaire circuits parallel to the window façade dim automatically according to available daylight levels via ceiling-mounted illuminance sensors and turn off completely when occupancy sensors no longer detect activity. Users can manually adjust the light output between 0% and 100% via a control panel at the entrance of each room. Shading consists of black, manually-operated, perforated interior roller blinds with 50% openings. These also serve for reducing light levels for media presentations during teaching.

Monitoring

Researchers from Aarhus University's Lighting Design Research Group established Navitas as a testbed for trialling established and novel ways of assessing integrated daylighting and electric lighting in the fall of 2019. A typical office space for academic staff (04.103) was fitted with various illuminance sensors, as well as two Raspberry-Pi computers with fisheye-lens cameras, whereas eight other offices and classroom spaces (fig. 4) were each fitted with

Figure 3. Typical classroom (04.121) at Navitas.

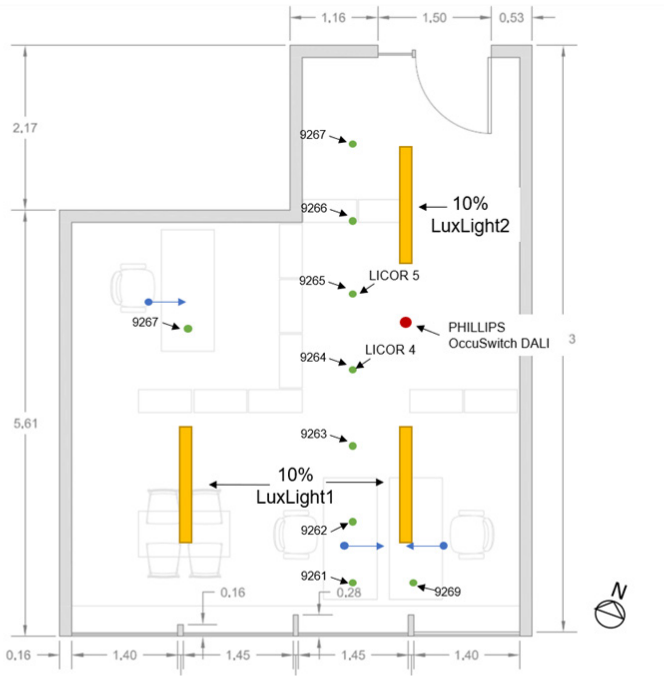

Figure 5. Floorplan of representative office (04.103) with installed luminaires and placement of illuminance sensors and luminance measurement locations (blue arrows).

a Raspberry-Pi at the ceiling centre looking at the floor. Long-term illuminance measurements every 15 minutes over a period of nearly 2.5 years until June 2021 were made in 04.103 (fig. 5). The Raspberry-Pi computers recorded luminance maps of the room surfaces in all rooms every 15 minutes (fig. 6). Luminance maps were used to assess illuminance levels (via surface reflectance values) and positions of manually operated window blinds. Measured readings were compared to data from the BMS gathered by in-ceiling light and occupancy sensors installed in the respective rooms and resulting light output values (0% = lights off; 100% = lights fully on). Supplementary spot luminance, vertical illuminance and spectral values were recorded at selected times at the workstations from the perspective of the user. The COVID-19 situation severely restricted which data could be used for analysis, as the lock-down limited access to the building and lighting systems were off for most of the time. The case study thus focussed on exploring connections between various lighting, energy and user aspects.

Energy

As part of the energy assessment for the offices and classrooms, data from the BMS for the nine spaces were

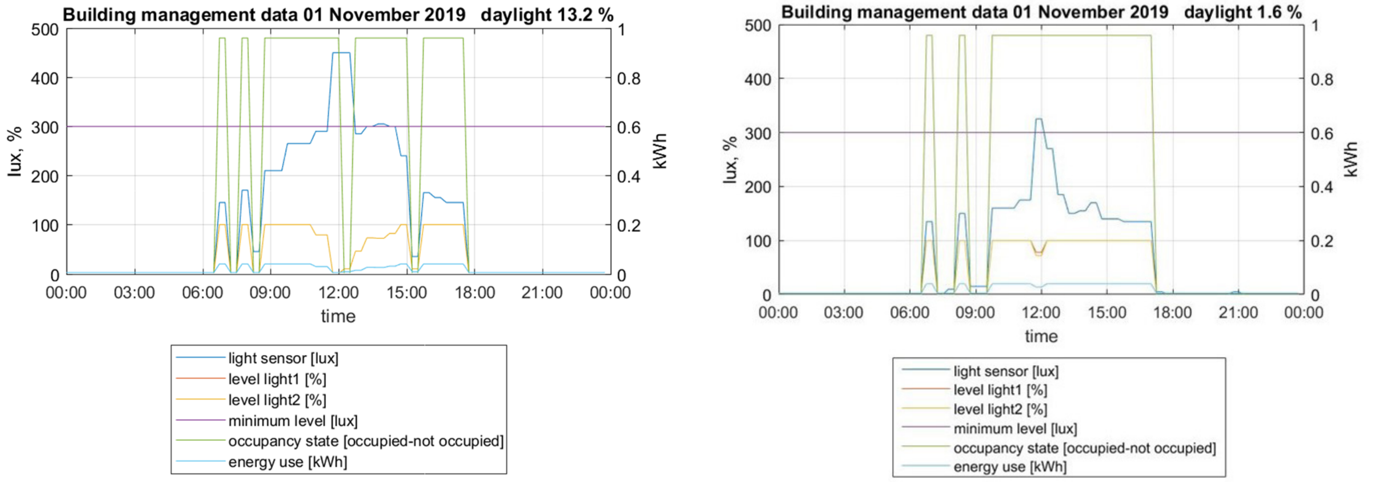

Figure 6: Building management system data for rooms 04.103 (left) and 04.106 (right) for 01 November 2019 showing detected illuminance level and light output percentage for the respective circuits, desired minimum illuminance at 300 lux, occupancy state (30 minute delay) and energy use.

reviewed. However, the long lockdown periods and only periodic use of Navitas for essential project work do not reflect normal use and energy consumption patterns. Emphasis was thus placed on assessing those aspects likely to affect energy use negatively. At present, the electric lighting turns on automatically when the detected illuminance levels are below the set-point when a person enters a room and stays on for a minimum of 30 minutes, even when users only briefly enter a room and leave again. A manual on-switch at the door would enforce deliberate action by an occupant, who may decide not to turn on the light in such a case. In September 2020, an unexplained error in the BMS raised the desired illuminance setting from 300 to 900 lux. Electric lighting would have failed to dim as the daylight levels alone never reached 900 lux below the in-ceiling sensors. Had it not been for this project, the error might not have been detected. User behaviour with respect to operating the manual roller blinds in offices and classrooms (see also under Photometry) was found to be a major factor in energy use. Active users frequently change the blind settings in response to daylighting conditions and direct sunlight penetration. Passive users often leave the blinds in a specific "workable" position for longer periods of time. Motorised blinds that move up at the end of each day and require new action by the user(s) the next day could increase daylight availability in and reduce energy for electric lighting.

Photometry

Measurements in 04.103 indicate that a daylight factor of at least 2.1% or 300 lux for half of the daylight hours across the year (EN 17037) can be reached 2.5m into the room from the façade. Most of the workstations at Navitas are located along the building's exterior façade. The desk in the north-west corner of 04.103 does not receive sufficient daylight. In classrooms with a depth of 8 to 10m from the façade, however, two thirds of the area fall below the 300 lux threshold from daylight alone, requiring electric lighting for most of the occupied hours. Electric lighting reaches on average 250 lux on the working plane. Below the luminaires, levels reach between 300 and 350 lux, but the workstation in the north-west corner of the room only receives 50 to 100 lux. Figure 6 shows an example of electric lighting performance based on data from the BMS for the nearly identical rooms 04.103 and 04.106 for a day with similar occupancy schedules. After the cleaning staff activities (two short peaks), academic staff arrive around 08:30 in 04.103 (left) and around 09:30 in 04.106 (right). Electric lights turn off 30 minutes after the last detected occupant movement. During midday, electric lighting turn off in 04.103 due to sufficient available daylight detected by the in-ceiling light sensor and occupants leaving. The lights in 04.106 stay on due to continuing occupancy, but are slightly dimmed as the lux level moves above 300 lux. The detected light levels are lower for 04.106 throughout the day, resulting in higher energy use. Daylight alone covers 13.2% of the occupied time in 04.103, but only 1.6% in 04.106. Luminance map images clearly show that blinds in 04.106 were pulled down about half-way, while blinds in 04.103 were fully open. Users had not moved the blinds in 04.106 between 22 October and 4 November 2019, whereas users in 04.103 actively adjusted blinds based on conditions in the room.

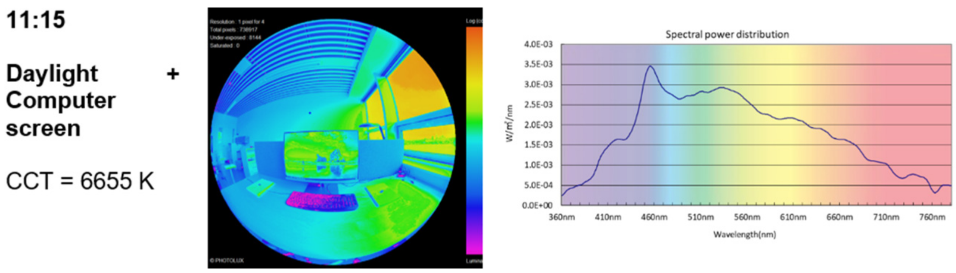

Figure 7. Recorded luminance map (left) and spectral power distribution for daylight and the computer screen (right) for a workstation adjacent to the window in room 04.103 at 11:15 on 21 January 2020. The vertical illuminance measured at the eye was 183.4 lux.

Circadian potential

Spectral information, appropriately weighted, allows for assessment of the circadian potential of different

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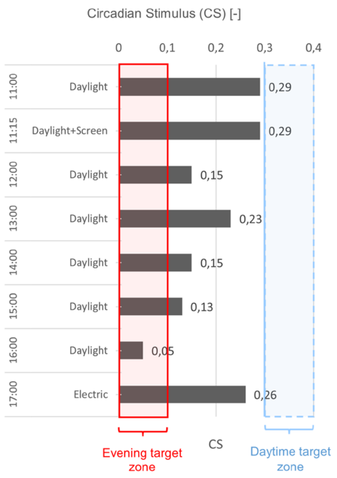

Figure 8. Circadian Stimulus (CS) calculated for a vertical illuminance at a height of 1.2 m above the floor in front of the computer screen. The target zones refer to the recommendations of the Lighting Research Center, Troy, NY.

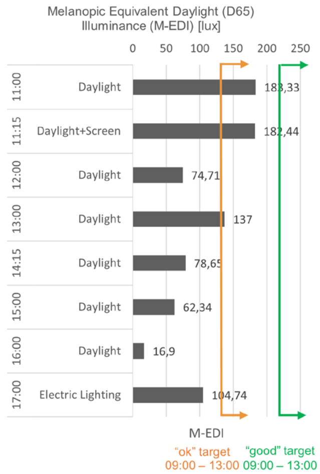

Figure 9. Melanopic Equivalent Daylight (D65) Illuminance (M-EDI) calculated by CIE Toolbox for a vertical illuminance at a height of 1.2 m above the floor in front of the computer screen. The target limits refer to WELL building standard v2.

lighting scenarios (fig. 7). The circadian potential expresses how a specific lighting scenario could support a building occupant's daily sleep/wake rhythm and well-being. This was evaluated using two metrics: the Melanopic Equivalent Daylight (D65) Illuminance (M-EDI) and the Circadian Stimulus (CS). Spectral power distributions (SPDs) were measured at workstations at a height of 1.2 meters at different times during the day. The results for on 21 January 2020 indicate CS values of between 0.05 and 0.26 for "daylight" and 0.26 for "electric lighting", and M-EDI values between 16.9 lux and 183.33 lux for "times with daylight" and 104.74 lux for "electric lighting" (figs. 8 and 9). For electric lighting alone, both CS (0.26) and M-EDI (104.74 lux) have been calculated as being too low for "ok" and "good" target zones. This suggests that occupants starting work during winter mornings will not receive sufficient circadian stimulus from the ceiling luminaires. Daylight at 11:00 does not fulfil the recommendations for the "good" target of 218 lux M-EDI, but reaches the "ok" target of 136 lux M-EDI. During the summer, the circadian stimulus at workstations near the window would be sufficient.

User perspective

The study was severely affected by COVID-19 impacts. Only essential operations or research activities needing access to specialised laboratories were permitted during lockdowns. Offices and classrooms stood vacant. The planned structured user surveys could not be conducted. User experience reports were thus relying on informal comments made prior to the lockdown in March 2020. Most users seemed generally satisfied with the spaces they occupy, especially with the view to harbour or city. Spaces facing into inner courtyards or the atrium were found to be less desirable. A repeating concern was inadequate window glare protection. Direct sunlight striking the roller blinds was penetrating the perforated fabric, creating high luminance contrasts. Direct sunshine penetrating the blinds also interferes with media presentations when teaching and can reflect into students' eyes. Some users had asked for opaque roller blinds in addition to the black perforated blinds. These reduced glare, but also the view out. Others suggested that exterior shading devices would be more effective in preventing overheating, especially since operable windows are few and small. The desire for manual electric light switches near doors and the reduction in energy use has already been mentioned above. A few users expressed desire for relocating the in-ceiling light sensor. Its current location near the door results in its inability to "see" some of the occupants located in the corners of a room. Lights turn off when only occupants in such locations are present. Users must then get up and move closer to the sensor to turn lights back on. Others mentioned that luminaires were mounted with their long axis perpendicular to the viewing direction for most desk locations in offices and classrooms. The brightness of fluorescent tubes is thus directly viewed by occupants looking straight ahead. This can result in an experience of glare, especially at night.

Carefully considering all aspects of integrated daylighting, electric lighting and shading design can make all the difference for a highly desirable user experience and low energy use.

One should never underestimate the power of simple, often low-cost measures that are thought through in all details.

Lessons learned

This case study emphasises the importance of carefully considering all aspects of integrated lighting. The Navitas building already meets the stringent "Energy Class 1" requirements of the 2015 Danish Building Regulations. Seemingly small issues like in-ceiling sensor locations, manual on-switches for lighting, as well as window blinds that are effective against glare and move automatically into the fully open position at the end of the day could further reduce lighting energy use and improve user satisfaction.

Further information

T. Baumann, M. Gkaintatzi-Masouti and W. Osterhaus. Luminance maps for investigation of lighting in indoor environments from HDR images with the use of a Raspberry Pi computer. Proceedings of LICHT 2021 – Nach Leuchten. Bamberg, Germany, 21-24 March 2021, pp. 506-520, https://licht2021.de/sites/default/files/LICHT2021_Online_Tagungsband.pdf

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