SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Subtask A: User perspective and requirements

A.2 Use cases

IEA SHC Task 61 / EBC Annex 77: Integrated Solutions for Daylighting and Electric Lighting

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Subtask A: User Perspective and Requirements

Use cases

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PREFACE

Lighting accounts for approximately 15 % of the global electric energy consumption and 5 % of greenhouse gas emissions. Growing economies, higher user demands for quality lighting and rebound effects as a result of low priced and more versatile electric lighting continuously still lead to an absolute increase of lighting energy consumption. More light is used, often less consciously.

Especially the electric lighting market but as well the façade, daylighting und building automation sectors have seen significant technological developments in the past decade. However these sectors still act mainly independent of each other, leaving out big potentials lying in a better technology and market integration. This integration is on the one hand beneficial to providing better user-centred lighting of indoor spaces. On the other hand it can contribute significantly to the reduction of worldwide electricity consumptions and C02-emissions, which is in line with several different governmental energy efficiency and sustainability targets.

IEA SHC Task 61 / EBC Annex 77 "Integrated Solutions for daylighting and electric lighting – From Component to system efficiency" therefore pursues the goal to support and foster the better integration of electric lighting and daylighting systems including lighting controls with a main focus on the non-residential sector. This includes the following activities:

- Review relation between user perspective (needs/acceptance) and energy in the emerging age of "smart and connected lighting" for a relevant repertory of buildings.
- Consolidate findings in use cases and "personas" reflecting the behaviour of typical users.
- Based on a review of specifications concerning lighting quality, non-visual effects as well as ease of design, installation and use, provision of recommendations for energy regulations and building performance certificates.
- Assess and increase robustness of integrated daylight and electric lighting approaches technically, ecologically and economically.
- Demonstrate and verify or reject concepts in lab studies and real use cases based on performance validation protocols.
- Develop integral photometric, user comfort and energy rating models (spectral, hourly) as pre-normative work linked to relevant bodies: CIE, CEN, ISO. Initialize standardization.
- Provide decision and design guidelines incorporating virtual reality sessions. Integrate approaches into wide spread lighting design software.
- Combine competencies: Bring companies from electric lighting and façade together in workshops and specific projects. Hereby support allocation of added value of integrated solutions in the market.

To achieve this goal, the work plan of IEA SHC Task 61 / EBC Annex 77 is organized according to the following four main subtasks, which are interconnected by a joint working group:

- Subtask A: User perspective and requirements
- Subtask B: Integration and optimization of daylight and electric lighting
- Subtask C: Design support for practitioners (Tools, Standards, Guidelines)
- Subtask D: Lab and field study performance tracking
- Joint Working Group: Evaluation tool & VR Decision Guide

Subtask A started with the wide literature review of user needs, which is presented in report A.1 User needs and requirements. Then, a registration of use of buildings and lighting systems have been done in different buildings in Europe. Parallelly, the literature review of use of buildings was done, and is presented in the present report.

The final result of Subtask A, where the collected knowledge about user groups has been transformed into Personas, will be presented in the report A.3 Personas.

EXECUTIVE SUMMARY

The report starts with the introduction, chapter 1, where the main objective of the work is formulated, namely, to examine how the public buildings are used regarding lighting; both daylight and electric light is considered.

In the chapter 2 a review of codes and requirements has been done. It starts with a discussion about general aspects of codes (subchapter 2.1) and presentation of international standards CEN and ISO (2.2) and follows with description of CIE reports and other internationally recognized guidance books (2.3). Then national recommendations are also presented (2.4). Finally, the impact of codes on architectural design is elaborated based on the interviews with architectural offices (2.5).

Chapter 3 presents the studies of buildings usage based on the extensive literature review. The following public building types are included: offices, schools, university buildings, hospitals, commercial buildings, industry buildings and libraries.

Chapter 4 focuses on occupancy and use of lighting systems. It starts with a discussion of the occupancy simulations and their usefulness in the current project context. Then, it follows with occupancy registration and use of lighting in chosen buildings located in different European countries. It includes registration in an office building in Italy, a primary school building in Norway, a university building in Poland and one industry building, also in Poland. The research method used in registration consisted of simultaneous registration of occupancy and use of (day)lighting with the help of a self-report diary, and light-technical measurements. The diary registration and the measurements were performed at the same day, in most cases in February/March 2020, that is just before the pandemic lock-down in Europe. Then, the use of electric light had been compared with the occupancy and (day)light level indoors/outdoors. The registration was carried out in each of the buildings for one day only. As such, it should be considered a form of stick sample to check the findings from the literature study presented in the chapter 3. Computer simulations were done for school and university buildings to estimate the light level during the whole year.

The registration confirms a pattern of occupants' behaviour found in literature. In general, occupants consider the visual environment at the workplace when they enter or leave the room. It happens mainly at the beginning (adjustment of blinds and switching on the electric light) and at the end of the working day (switching of the light). The use of lighting follows occupancy pattern, and not daylight level outdoors, something that indicates significant potential for energy saving.

Chapter 5 Conclusions conveys general results regarding codes and more specific results regarding use of the different building types.

Contents

Contents **8**

1 Introduction **10**

2 Building codes and requirements **11**

2.1 General aspects of codes 11

2.2 International standards CEN and ISO 12

2.3 CIE standards, reports, or good guidance handbooks 13

2.4 National building codes (daylight) 14

2.5 Other recommendations (daylighting) 15

2.6 The impact of codes on architectural design 20

2.7 Overall conclusions 26

3 Literature review of building use **27**

3.1 Literature review methodology 27

3.2 Offices 29

3.2.1 Energy 30

3.2.2 Space use: occupancy detection 31

3.2.3 Light 32

3.3 Schools 36

3.3.1 User-centred design 38

3.3.2 The influence of indoor environmental quality in primary schools and kindergartens buildings 40

3.3.3 Lighting energy saving potential and comfort perception in classrooms 41

3.4 University buildings 42

3.5 Hospitals 45

3.5.1 Evidence-based design 46

3.5.2 End-user perceptions 47

3.5.3 Neonatal intensive care unit lighting 47

3.5.4 The influence of the workplace indoor environmental quality on the incidence of psychological and physical symptoms in intensive care units 48

3.5.5 Energy saving in hospital patient rooms: the role of windows size and glazing properties 49

3.5.6 Study of indoor environmental quality and occupant overall comfort and productivity in certified healthcare settings 49

3.6 Commercial buildings 52

3.6.1 Atmospheric elements as a marketing tool 52

3.6.2 The influence of lighting on user behavior 53

3.6.3 User cultural context (Perception of brightness, CCT and CRI) 54

3.6.4 Development of lighting technology and energy concerns 54

3.6.5 Difficulty of tracking the long-term and short-term occupants 55

3.6.6 Occupant behavior agent-based modelling 55

3.6.7 Daylight 56

3.6.8 Atrium and glazed spaces 56
3.6.9 Lighting control strategies 57
3.7 Other public buildings 60
3.7.1 Industry buildings 60
3.7.2 Libraries 60
3.8 Overall conclusions 61
4 Occupancy and use of lighting systems 63
4.1 Simulation of occupancy 63
4.1.1 Introduction 63
4.1.2 Simulation of occupancy in the scope of Subtask A 63
4.1.3 Conclusion 66
4.2 Registration of occupancy and use of lighting with a diary method 67
4.3 Registration in Office building 68
4.3.1 Introduction 68
4.3.2 Methodology 69
4.3.3 Results 71
4.3.4 Conclusions 74
4.4 Registration in School buildings 75
4.4.1 Introduction 75
4.4.2 Methodology 76
4.4.3 Finding/Results 78
4.4.4 Conclusion 88
4.5 Registration in university building 89
4.5.1 Introduction 89
4.5.2 Methodology 89
4.5.3 Results 90
4.6 Registration in Industry building 94
4.6.1 Introduction 94
4.6.2 Methodology 94
4.6.3 Results 96
5 Conclusions 100

1 Introduction

This report has been developed in the frame of the IEA Task 61 Subtask A User perspective and requirements. The main objective was to examine use of public buildings with the focus on lighting. Both, daylight and electric light, were considered.

The work started with the review of international and national codes and recommendations in countries participating in the IEA SHC Task 61 and beyond.

The use of buildings has been studied through the extensive literature review focusing on boundary conditions and use patterns of various categories of buildings: office buildings, schools, university buildings, commercial and industry buildings.

The occupancy simulator was tested on one office building located in Poland.

In addition, the field-study of occupancy and use of lighting using the Self-Report method has been carried out in Norway, Poland and Italy. It resulted with updated occupancy data for schools, offices and commercial buildings, which can be relevant also in other countries.

The results from this report will be used in development of Personas, report A.3, which is the final result of Subtask A activities.

2 Building codes and requirements

The criteria of what stands for good lighting and what kind of metrics to adopt are not universal. The ways how to provide and evaluate lighting within the built environment are partly depicted by standards, codes and national building recommendations. The mandatory regulations influence the way the architecture is created. They should be clear, reliable, testable, and reasonable to be able to inform and guide the designer. However, it is often not a case. This chapter is an attempt to explain the matrix of building codes and daylight, electric light standards. It presents part of a discourse about universal lighting metrics and statutory regulations.

2.1 General aspects of codes

The necessary amount of light to be provided and the ways to achieve it are usually specified in various national lighting, building or energy efficiency documents published by the authoritative bodies. Following recommendations will not ensure the excellent quality of lighting design, but they usually help to prevent poor daylight decisions (Boyce, 2003). Also, not the best theory nor the best executed calculations ensure the 'good quality' lighting but they are fundamental to the design of buildings. A complexity and subjectivity of daylight design is illustrated in historical and current European and national daylight regulations, which present many agendas of how to measure, execute or provide 'good daylight' and what 'good quality daylight' really means. There is also an ongoing discourse between academics and practitioners if the daylight standards are really needed and if yes, how they should regulate, codify, introduce design measures to be beneficial not only restrictive, see the references for 2.1 Part of this discourse is depicted in an exchange of views between P. Tregenza and J. Mardaljevic in a paper, which they co-authored for Lighting Research and Technology aiming at summarizing earlier articles which had been published in this journal for the last 50 years. They both agreed that current situation is not satisfactory, especially regarding the lack of consistency in daylight criteria, metrics, and regulations (especially in non-visual responses to light metrics era). P. Tregenza offered a review of standards' nature, types, and requirements of daylight prediction methods (Tregenza and Mardaljevic, 2018), starting with defining what a good standard should be.

Its outcome must be beneficial; it must be clear; the conditions required for conformity must be:

- few
- obviously related to the purpose
- testable within a realistic time and at a reasonable cost
- capable of giving consistent results when repeated or reproduced by different assessors
- capable of being used by all relevant parties

Three proposed distinct levels of daylighting examination are partly based on design intentions and technical aspirations to help to formulate the objectives and characteristics of the metrics and regulations. The levels are:

- minimum acceptable conditions
- good current practice
- innovative design and research

The amount of recenlty published papers also illustrate the ambiguities concering the "good" electric lighting and daylighting criteria, especially in non-visual responses to light metrics' era.

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Boyce, P. R. (2003) 'Codes and consequences', in *Human Factors in Lighting*. 2nd edn. London: CRC Group, Taylor & Francis Group, pp. 399–521.

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2.2 International standards CEN and ISO

The cautious study of different national regulatory publications may also illustrate the earlier signalised issues like a lack of coherence between diverse metrics and lighting appraisal methods, as well as a growing number of various criteria and ideas how to handle variety of electric lighting and daylight occurrences and its changing characteristics.

Some of the daylighting and lighting related recommendations depicted from the national lighting standards, energy regulations or building codes from the selected European countries, are presented in Table 2.1. The assembled data illustrate that there are several kinds of national documents where daylight requirements are introduced. Depending on the legislative system they fall into four main categories:

- laws
- approved documents
- standards
- different kind of guidance documents (assuring regulatory compliance) (Raynham 2015).

They often refer to each other or to another mandatory documents related to energy efficiency of the built environment. Daylighting criteria can be typically found in building regulations, energy efficient mandatory documents, and lighting standards.

The building standards often refer to lighting, and energy efficiency ISO (the International Organization for Standardization) and CEN (European Committee for Standardization) documents which are approved by different international standardization discipline–oriented committees.

- BS 8206-2: 2008: Lighting for buildings: Code of practice for daylighting, London: BSI.
- BS 5489-1:2003+A2:2008. Code of practice for the design of road lighting. Lighting of roads and public amenity areas
- EN 13363-1:2003 + A1:2007 Solar Protection Devices Combined with Glazing - Calculation of Solar and Light Transmittance - Part 1: Simplified Method
- EN 13363-2:2005/Ac:2006 Solar Protection Devices Combined with Glazing - Calculation of Total Solar Energy Transmittance and Light Transmittance - Part 2: Detailed Calculation Method
- EN 14501:2005 Blinds and Shutters - Thermal and Visual Comfort - Performance Characteristics and Classification
- EN 15193:2007 Energy Performance of Buildings - Energy Requirements for Lighting
- EN 15251:2007 Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics
- EN 15193/Ac:2010 Energy Performance of Buildings - Energy Requirements for Lighting
- EN 12464-1:2011 Light and Lighting - Lighting of Work Places - Part 1: Indoor Work Places
- EN 17037 Daylight of Buildings (2018)
- EN 12665:2011 Light and Lighting - Basic Terms and Criteria for Specifying Lighting Requirements
- EN 410:2011 Glass in Building - Determination of Luminous and Solar Characteristics of Glazing
- EN ISO 11664-2:201145 Colorimetry - Part 2: CIE Standard Illuminants
- EN ISO 11664-3:2013 Colorimetry - Part 3: CIE Tristimulus Values
- ISO 8995-1:2002 Lighting of Work Places – Part 1: Indoor
- ISO 15469:2004 (CIE S 011/E:2003) Spatial Distribution of Daylight—CIE Standard General Sky

- ISO 16813:2006 Building Environment Design – Indoor Environment – General Principles Building
- ISO 16817:2012 Environment Design – Indoor Environment – Design Process for Visual Environment
- ISO 19454:2019(E) Building Environment Design — Indoor Environment — Daylight Opening Design for Sustainability Principles in Visual Environment
- ISO 23045:2009 Building Environment Design - Guidelines to Assess Energy Efficiency of New Buildings
- ISO/CIE CD TR 21783 Light and Lighting – Integrative Lighting – Non-visual Effects

Referencing and cross-referencing to existing documents can help the user of the new standard learn more about genesis and the related field of scope. For example, the recent EN 17037 *Daylight in buildings* standard refers to the current European lighting standards:

- EN 12665:2011, Light and lighting – Basic terms and criteria for specifying lighting requirements
- EN 12462-1:2011, Light and lighting – Lighting of Workplaces – Part 1: Indoor Workplaces
- EN 15193-1, Energy performance of buildings – Module M9 – Energy requirements for lighting - Part 1: Specifications

The mentioned EN 17037:2018 *Daylight in Buildings* gives the recommendation, among others, for:

- the minimum recommendations for achieving an adequate subjective impression of lightness indoors.
- the criteria for minimum daylight provision; daylight illuminance level of 300 lx is exceeded over 50% of the area, and daylight illuminance level of 100 lx is exceeded over 95% of the relevant area of the space for more than half of the daylit hours in the year for façade widow
- the calculation methods for the minimum daylight provision; two methods of evaluation are suggested i) calculation of daylight factors or ii) calculation of indoor illuminances on the reference plane on a short time steps using validated software and climatic data for the given site
- the provision of an adequate view out; detailed criteria for a minimum horizontal sight angle, a minimum external view distance as well as visibility of view layers (sky, landscape, or ground) are given.
- the duration of sunshine exposure, the criteria for minimum exposure to sunlight are given for a randomly selected day between 01. February and 21. March and a minimum elevation angle of the sun at the given location
- the minimum protection from glare, a recommendation to use Daylight Glare Probability (DGP)

The idea behind the EN 17037 is helping to define minimum daylighting criteria for successfully daylit spaces. The standard considers the traditional daylight indicator (daylight factor) and introduces the climate base dynamic metric, the Daylight Provision. The standard emphasises that daylight is strongly favoured by building occupants. Anyway, none of daylight circadian metrics are mentioned.

2.3 CIE standards, reports, or good guidance handbooks

The International Commission on Illumination (CIE), apart of the work on lighting standards, also publish technical reports which cover the state-of-art positions on different aspects of lighting applications.

The report CIE S 026/E:2018 *System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light* doesn't give any quantitative prediction to the non-visual responses of light but tackles retinal photoreception issues. It defines spectral sensitivity functions, quantities and metrics to describe the ability of optical radiation to stimulate each of the five photoreceptor types that can contribute, via the melanopsin-containing intrinsically-photosensitive retinal ganglion cells (ipRGCs), to retina-mediated non-visual effects of light in humans. The document is applicable to visible optical radiation in the wavelength range from 380 nm to 780 nm. In addition, the document includes information concerning the effects of age and field of view (FOV) when quantifying retinal photoreceptor stimulation

The CIE report 016-1970 *Daylight* focuses on guidance and aid for architects, civil engineers, building inspectors, and others concerned with the natural lighting of buildings. It is currently under the revision in the Division 3.

Other documents, like CIE 222:2017 *Decision Scheme for Lighting Controls in Non-Residential Buildings* illustrate the process of lighting design (electrical and daylight) within non-residential buildings.

Also, the CIE 158:2009 Ocular Lighting Effects on Human Physiology and Behaviour should be mentioned as relevant.

National lighting organisation also publish good guidance handbooks and codes, which assure regulatory compliance. For instance, the Chartered Institution of Building Services Engineers (CIBSE) throught the Society of Light and Lighting (SLL) from the UK recommends publications:

<u>General guidance</u>

- SLL Code for Lighting (2012)
- SLL Lighting Handbook (2018)

<u>The function-specific guidance publications</u>

- SLL Lighting Guide 0: Introduction to Light and Lighting (2017)
- SLL Lighting Guide 1: The Industrial Environment (2012, updated 2018)
- SLL Lighting Guide 2: Lighting for healthcare premises (2019)
- SLL Lighting Guide 4: Sports (2006)
- SLL Lighting Guide 5: Lighting for Education (2011)
- SLL Lighting Guide 6: The Exterior Environment (2016)
- SLL Lighting Guide 7: Offices (2015)
- SLL Lighting Guide 8: Lighting for Museums and Art Galleries (2015)
- SLL Lighting Guide 9: Lighting for Communal Residential Buildings (2013)
- SLL Lighting Guide 10: Daylighting - A Guide for Designers: Lighting for the Built Environment (2014)
- SLL Lighting Guide 11: Surface Reflectance and Colour (2001)
- SLL Lighting Guide 12: Emergency Lighting (2015)
- SLL Lighting Guide 13: Lighting for Places of Worship (2014, updated 2018)
- SLL Lighting Guide 14: Control of Electric Lighting (2016)
- SLL Lighting Guide 15: Transport Buildings (2017)
- SLL Lighting Guide 16: Lighting for Stairs (2017)
- SLL Lighting Guide 17: Lighting for Retail Premises (2018)
- SLL Lighting Guide 18: Lighting for Licensed Premises (2018)
- SLL Lighting Guide 19: Lighting for Extreme Conditions (2019)

The Codes are intended to communicate measurable minimum standards across different professions targeting lighting-decision makers and professionals within the built environment.

2.4 National building codes (daylight)

In general, these documents refer to most crucial aspect of daylight parametrisation and evaluation. Most national regulations stipulate specific criteria for control of the built form through:

- a preferred orientation of windows to ensure the minimal solar gain
- window to floor area ratio
- window to wall area ratio
- the minimum distances between neighbouring buildings, to avoid overshadowing.
- preferable values of daylight factor (D)
- required insolation periods.

The 2.1 specifies the chosen cross-country recommendations depicted from national building regulations concentrating on the building window to floor ration, daylight and sunlight provision, view out and distances between buildings. Parametrisation found in the national building standards and design practices are often analysed in various review publications or simplified in architects' practical reference publications like (Neufert and Neufert, 2000). Internationally used architectural manuals provides information about lighting technicalities and basic rules for room layout orientations.

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1. Neufert, E. and Neufert, P. (2000) *Ernst and Peter Neufert Architects' Data*. 3rd edn. Edited by B. Baiche and N. Walliman. Blackwell Science.

2.5 Other recommendations (daylighting)

Only a few nations (among them Slovakia, the Czech Republic, Sweden, the UK, France) had the separate standards or guidelines on daylight provision for the specific types of building environments. The investigated regulations in less or more restrictive manner focus on a control of the built form and a way for daylight provision. The unique UK regulation *Right to Light* (The Law Commission, Commission and Law Commission, 2014) ensures that daylight availability in existing buildings could not be reduced by changes to neighbouring buildings. The layout of the buildings and orientation of the rooms are also the subjects of British good practice guidebooks, such as Lighting for Communal Residential Buildings (Chartered Institution of Building Services Engineers CIBSE, 2013) and P. Littlefair's *Site layout planning for daylight and sunlight. A guide to good practice.* (Littlefair, 2011). The criteria of the minimum solar gain in winter was presented in Danish guidelines.

Summary of principles and criteria found in the green building certifications systems like:

- LEED (Leadership in Energy and Environmental Design, USA);
- BREEAM (Building Research Establishment Environmental Assessment Method, UK);
- CASBEE (Comprehensive Assessment System for Built Environment Efficiency, Japan);
- BCA Green Mark (Singapore);
- Green Star (Australia);
- International WELL Building Standard

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1. Littlefair, P. J. (2011) *Site layout planning for daylight and sunlight. A guide to good practice.* second. Garston: IHS BRE Press.

2. Neufert, E. and Neufert, P. (2000) *Ernst and Peter Neufert Architects' Data*. 3rd edn. Edited by B. Baiche and N. Walliman. Blackwell Science.

3. The Law Commission, Commission, L. and Law Commission (2014) *Rights to Light*. London.

4. Lighting for Communal Residential Buildings (Chartered Institution of Building Services Engineers CIBSE, 2013)

Table 2.1: Daylight recommendations in building codes in selected countries.

COUNTRY BUILDING CODE	DAYLIGHT RECOMMENDATIONS
BRAZIL	
Brazilian Association of Technical Standards – Brazilian Standard ABNT NBR 15.575 (2013) – Residential building´s performance [1]	Illuminance level at the middle of space (restrooms, bedrooms, kitchens, bathrooms, and laundries) must be higher than 60 lux; D for the same spaces must be at least 0,50%. Calculation must be done for partially overcast sky (50% nebulosity), 9:30 am and 15:30 pm, on 23 April and 23 October. This is under revision since 2018 – the new proposal includes dynamic metrics: a fraction of space must be illuminated by daylight during a fraction of annual daylight hours.
Standard of National Institute of Metrology –INI-C- for Commercial, Services and Public Buildings (2021) [2]	In order to obtain label "A" in energy efficiency, buildings must inform the potential of daylight integration with lighting systems (daylight autonomy of 300 lux at least 50% of daylight annual hours). But there is no minimum of daylight integration or daylight autonomy required.
Regional Building Codes	Regional Building Codes – minimum of 1/6 to 1/8 window surface/floor area depending on city/region
ITALY	
Legislative Decree of the Ministry of Health [3]	In Schools average D should be: 3% in classrooms for lessons, study, reading, laboratories, drawing, etc; 2% in gym and canteen; 1% in offices, corridors, stairs,

	toilets, connecting spaces.
Legislative Decree of the Ministry of Health [4] Legislative Decree [5]	In the case of premises (shops, stores…) not intended for residential use, the openable surface of the windows must be not less than: - 1/8 of the useful area of the room if the area of the room is less than 100 square meters, - 1/10 of the useful area of the room, with a minimum of 12,5 square meters, if the area of the room is between 100 square meters and 1000 square meters, - 1/12 of the useful area of the room, with a minimum of 100 square meters, if the area of the room is over 1000 square meters. In general, the designers have to take into account the exploitation of daylight and its integration with artificial light while guaranteeing an appropriate level of visual comfort.
ITACA Reference Practice (often embedded in regional and district non-residential building codes) [6]	Reference limit for DF: Office 2%; Corridors, stairs, connecting spaces 1%; Commercial building 2%, Industrial building 1%, Hotel 1%; Restaurant 2%; Library and reading room 2%; Museum and exhibition hall 1%.
JAPAN	
-Building Standard Law [7,8]	-habitable rooms of houses, schools, hospitals, clinics, dormitories, boarding houses and other buildings should have openings such windows for daylighting -the ratio of the opening area effective for daylighting to the floor area shall not be less than 1/7 in houses, sickrooms of hospitals and clinics, bedrooms of dormitories and boarding houses, 1/5 in classrooms of kindergartens and elementary-, junior-high-, high-, and other compulsory-education schools and 1/10 in classrooms of other types of school -two rooms separated by Japanese sliding doors or other partitions that can be left open at all times are treated as one room when applied to the above criteria -there are rules to calculate the area effective for daylighting -the area effective for daylighting can be reduced for habitable rooms equipped with lighting installations that comply with the standard
THE NETHERLANDS	
-Building Decree Bouwbesluit, 2012 - NEN 2057 Daylight openings of buildings – Determination method of equivalent daylight of a space, 2011 [9,10]	-openings within two meters of the plot boundary will not be included in calculation -rooms should comply with a minimum daylight factor of 0.8% in 50% of the area and an average daylight factor of 1.5% also in 50% of the area. Besides the amount of daylight, sunlight, glare and view also influence the daylight quality and should be taken into account during the design process.
NORWAY	
-Norwegian Building Regulation TEK17 -European light standard – NS-EN-12464-1:2011 - ”Light and lighting - Lighting of workplaces - Part 1: Indoor work spaces’’ [11]	-rooms permanently occupied by people must have adequate access to daylight, average daylight factor in such rooms D □ 2,0% -the calculations must be performed with simulation programs validated according to CIE 171:2006 and with the assumptions given in NS-EN 12464-1:2011 chapter 4.4. -alternatively, a simplified method may be used: the area of glass located minimum 0,8m above the floor can be calculated using the parameters: usable area of the room and light transmittance of the glass - according to TEK17, Daylight Factor simulations should be performed with the assumptions from NS-EN-12464-1 including the illuminance grid calculations and reflectances.
POLAND	
The Regulation of the Minister of Infrastructure on the technical conditions to meet by buildings and their location [12]	-in permanently occupied rooms, the ratio of window area to the floor area should be at least 1:8, and in any other room, where daylight is required, the ratio should be at least 1:12 -conditions for exposure to sunlight, in permanently occupied rooms. The isolation time should be at least 3 hours during equinox days (21st of March and 21st of September) between 7am and 5 pm. -The distance of the building containing permanently occupied rooms form other objects shall allow natural lighting of such rooms – which shall be deemed to be

	fulfilled if: there is no screening part of the same building or other screening object from the screened room at a distance less than: a) the height of the screening – in case of screening facilities over 35 m in height, b) 35 m – in case of screening facilities over 35 m in height; - The height of the screening shall be measured from the height of the lower edge of the lowest windows of the screened building to the height of the highest shading edge of the screening object or its screening part - It is allowed to locate the screening object at a distance of not less than 10 m from the window of an obscured room, such as a mast, chimney, tower or other structures, without limiting its height, but with a screen width of no more than 3 m, measured parallel to the plane windows.
DENMARK	
-Danish Building Act, 2018 [13]	-In buildings where workplaces are arranged, the rooms must be designed considering their size, daylight, room height and room content in order to ensure that the room is dimensioned for the use and the number of persons expected to work there with due consideration of health, safety and functionality in the room. -Buildings must have light conditions that ensure that no risk will occur to the health, safety and comfort of people. Sufficient daylight and view of the surroundings must be ensured as well as sufficient electric lighting with due consideration of the use. -Planning and construction must be carried out with due consideration of the following: 1) Daylight must be utilised as a source of light to the extent it is possible. (…) -glass surface without shadowing effect equivalent of minimum 10 per cent of the relevant floor area -Alternatively, sufficient daylight may be documented by proving that the inside lighting intensity from daylight is 300 lux or by for minimum half to the relevant floor area for minimum half of the daylight hours.
FRANCE	
-Code de la construction et de l'habitation, 2014 [14]	-1/6 window surface/floor area -room must have and opening area and transparent surface to the exterior
GERMANY	
-DIN 5034-1:2011-07 – Daylight in interiors – Part 1: General requirements [14]	-DF on average 0.9%, horizontal, 0.85 m above the floor and in 1m distance to walls in the middle of the room and -At least 0.75%, at the most unfavourable place
SLOVENIA	
- Rules on Minimum Technical Requirements for the Construction of Apartement Buildings and Apartments, 2011 - TSG-1-004:2010—Ecient Use of Energy [15,16,17]	-the "collecting area" (the roof and the facade) of a building is exposed to sun's rays 1 m above the ground (lower areas are not considered due to natural and built obstructions) at least 2 h on 21st of December, on the equinoxes (21st of March and September) at least 4 h, and at the summer solstice (21st of June) at least 6 h. (TSG-1-004:2010) -The second requirement for the daylighting of rooms in residential buildings in Slovenia stems from the rules on minimum technical requirements for the construction of apartment buildings and apartments. According to the stated rules, minimum natural lighting is achieved when the openings of a room have a surface of at least 20% of the room surface (i.e., window-to-floor ratio of 20%). Additionally, there is a limit to the depth and width of one-sidedly lit rooms. (Rules on Minimum Technical Requirements for the Construction of Apartement Buildings and Apartments; Ministry of the Environment and Spatial Planning of the Republic of Slovenia, 2011)
SWEDEN	
- Building code BFS 2014:3,	-Rooms or separable parts of rooms where people are present other than

2016:6 [18,19]	occasionally shall be designed and oriented to ensure adequate access to direct daylight is possible, if this does not compromise the room's intended use. -However, in common spaces according to Section 3:227, access to indirect daylight is sufficient. (BFS 2016:6) -For calculation of the area of the window glazing, a simplified method according to SS 91 42 01 can be used. The method applies for room sizes, window glazing, window placement and shielding angles according to the standard. When used, a general figure for the window glazing area in the room should be at least 10 % of the floor area. It entails a daylight factor of approximately 1 % if the conditions of the standard is met. For rooms with other conditions than those specified in the standard, the window glazing area can be calculated for the daylight factor 1.0 % according to the standard's annex. (BFS 2014:3). -Sunlight: At least one room or separable part of a room in dwellings, where people are present other than occasionally, shall have access to direct sunlight. However, student dwellings of not more than 35 m2 is not required to have access to direct sunlight. (BFS 2014:3).

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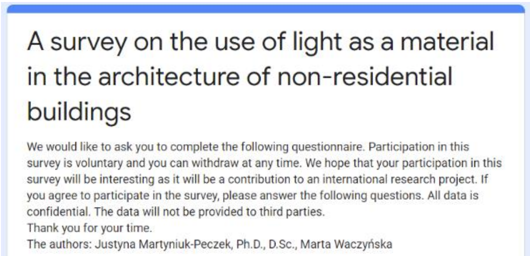
2.6 The impact of codes on architectural design

It is important to understand the impact of codes on architecture design. The research question that appeared during the review of standards was focused on an influence of the standards recommendations on the form of the building and the way light, especially daylight, is introduced to the building mass. Therefore, an online questionnaire was conducted with practicing architects who had designed non-residential buildings. The main purpose of the study was to determine the practical impact of the lighting requirements on architectural design decisions. The participants of the survey, the selected architects with a long practice, have been asked to select from their portfolio the project in which light had a great impact on their design solutions.

The questionnaire was prepared online in Google Forms: https://forms.gle/XgLfeiPMdpKuApYG7 (Figure 1):


A survey on the use of light as a material in the architecture of non-residential buildings

We would like to ask you to complete the following questionnaire. Participation in this survey is voluntary and you can withdraw at any time. We hope that your participation in this survey will be interesting as it will be a contribution to an international research project. If you agree to participate in the survey, please answer the following questions. All data is confidential. The data will not be provided to third parties.
Thank you for your time.
The authors: Justyna Martyniuk-Peczek, Ph.D., D.Sc., Marta Waczyńska

Figure 1. The first page of an online version of the questionnaire in English.

The online survey was designed using the Google Forms. Afterwards, the survey was distributed among participants and carried out from April to June 2020. Due to the international distribution, two language versions have been prepared: Polish and English. The participants were recruited via e-mail with request to complete a survey. Participation in the study was voluntary and each participant could withdraw from it at any time. The survey was constructed on the basis of single-choice and multiple-choice questions as well as open-ended questions. The questionnaire also included picture-based questions. This procedure was aimed at increasing the participants' interest in the discussed issue and clarifying the problem contained in the questions.

The questions in the survey were divided into 4 categories: introductory information, daylighting, electric lighting, summary questions. The survey required an answer to all the questions from a given category in order to be able to move on to the next one. In the first part of the survey, the participant was asked to choose one building and provide the preliminary information about the architect and selected project. The second part was focused on providing the design materials: documentation, object photographs and the building description. The third and the fourth parts were questions on respectively daylight and electric light. The last part offered the subjective questions regarding the biggest challenges associated with daylight and electric light.

Table XX. The structure of the survey.

Introductory information

1. Project name
2. Name of the authors of the project
3. Location
4. Investor (Private / Public)
5. The function of the object
6. Year of implementation

Design materials

7. Please put the files here:

8.Please provide your e-mail address for contact regarding the declaration of using photos in a publication as part of the IEA report.

Daylight

9. Please indicate whether the shape of the building in relation to the aspects of daylighting was taken into account

Yes / No

10. If you selected the "Yes" option in the previous question, please specify in which cases:

Open body (shaped by higher opening-to-closing ratio / A solid elongated in plan (allowing to illuminate the interior building) / Shaping the form (studying volume versus optimization daylight)

11. Please indicate which architectural elements for daylighting appear in the project:

Standard windows / Wall glazing – facades / Roof windows / Roof skylights / Roof domes / Blinds and shutters / Integrated facade elements - shaping the light distribution / Elements used to redistribute light (reflection of light to reach the interior building) / Other

12. Please specify the factors influenced by the day lighting in the project:

Location / The location of the object / Shape of the building / Elevation setting / Arrangement of window openings / Aesthetics / User needs / User comfort / Health related aspects / Other

13. Please indicate which factors governed the applied lighting solutions in the project:

Design idea / Investor's order / Country specific laws or regulations / Multi-criteria certification (e.g. LEED, BREEAM, …) / Day lighting regulations / User needs (e.g. type of tasks performed) / Other

14. If in the previous question you have selected the option "legal or other regulations appropriate for a given country "please provide the names of the documents: (open question)

15. Please specify to what extent the legal provisions had an impact on the adopted design solutions in the context of lighting conditions:

A very big impact / Huge impact / Neither big nor small / Little impact / Very little impact

16. Please indicate which analyses related to daylighting were made in the project:

Solar analysis (sun ruler) / Shadowing analysis / Analysis of the distance between buildings / Illuminance analysis / Daylight analysis (DF, sDA, …) / Analysis of the influence of daylight on the visual conditions inside (DGP, …) / Analysis of the view outside the window / Daylight related analyzes were not performed / Other

17. Please indicate in which design phase the analyzes related to daylighting were performed:

Initial design phase / Conceptual design / Construction project / Executive project / Analyzes related to daylighting were not performed / Other

Electric light

18. Please indicate which person made the selection of electric lighting in the project:

Architect / Electrician / External company - lighting consulting / Other (specify)

19. If the "architect" option was selected in the previous question, please determining what factors were taken into account when selecting the lighting electric:

Regulations / Aesthetics / The function of the facility and the type of activity of people staying in it / Other

20. Please specify what was the key criterion in aesthetic selection electric lighting:

The form of the lighting object / Visual guidance / Orientation in space / Other

21. Please specify what legal provisions were included in the design electric lighting: (open question)

Summary questions

22. Please specify in which design phase the lighting aspects had an impact on the design solutions adopted in the project:

Initial design phase / Conceptual design / Construction project / Executive project / Other

23. Please specify to what extent the lighting aspects have had an impact on design:

To a very large extent, they had a dominant influence compared to the other factors / To a great extent compared to other factors / To a similar degree compared to other factors / To a small extent compared to other factors / To a very small extent compared to other factors

24. Please describe the biggest challenges associated with daylighting design: (open question)

25. Please describe the biggest challenges associated with design electric lighting: (open question)

Three architects from three different countries took part in the survey: Ireland, the Netherlands and Poland. The architects came from the following offices: Heneghan Peng architects, Marquart Architecten and Grupa 5 Architekci. The following facilities were selected: the National Gallery in Dublin, the Rabobank headquarters in Oosterhou, and the office building at ul. Piękna in Warsaw. The participating architectural offices and the analysed projects are presented in the Table 2. The first project was the project of the National Gallery in Dublin designed by Hengean Peng. The project was finished in 2017 using public funds. The main objective of the design was a reconstruction of the galleries and a replacement of existing glazing to meet the requirements of the new artwork exhibitions. The second project analysed was the Main Office Building of Rabobank by Marquat Architects. The project was erected in 2012 with the funds from the private investor. The third one was the Office Building in Warsaw designed by Grupa 5 Architects in 2015-2019 on a very narrow plot located in a dense urban structure.

Table 2. The case study used in survey.

Survey on the use of light as a material in non-residential architecture			
	Case study-Ireland	Case study – The Netherlands	Case study - Poland
	1. General information		
Project name	***Reconstruction of the National Gallery in Dublin***	***Rabobank main office in Oosterhou***	***Office builidng in Warsaw***
Authors	*Heneghan Peng Architects, lighting design by Bartenbach Lichtlabor*	*Marquart Architecten*	Grupa5 Architekci
Localisation	*Merrion Sq., Dublin, Ireland*	*Oosterhout, The Netherlands*	Piekna St., Warsaw, Poland
Funding	Public	Private	Private
Function	Art gallery	Office	Office
Year	2017	2012	2015-2018
	2. Design		
Photographic documentation:	 (Source: https://en.wikipedia.org/wiki/National_Gallery_of_Ireland)	 (Source: Marquart Architecten, fot: Adriaan van Dam)	

			 (Source: Grupa 5 Architekci, fot: Mikołaj Lelewski)
	3. Legal requirements [8]		
Building regulations:	Irish Building Regulations - Technical Guidelines [1]	Bouwbesluit 2012 - establishing construction, use and demolition regulations [3]	Regulation of the Minister of Infrastructure of April 12, 2002 on technical conditions to be met by buildings and their location [6]
Regulations for daylight and electric light:	-BS EN 17037: 2018 Daylight in buildings [2] - Irish Building Regulations [1]	- NEN 3087 - Visual ergonomics in relation to lighting - Principles and applications [4] - NEN 2057 - Daylight openings of buildings - Determination method of the equivalent daylight area of daylight area of a space [5]	PN-EN 12464-1: 2012 -Light and lighting - Lighting of workplaces - Part 1: Indoor workplaces [7]
Detailed regulations:	- In rooms intended for work, the appropriate amount of daylight is defined as the ratio of the window area to the floor area of at least 10% for standard windows and 7% for roof windows - while maintaining the glazing light transmittance of 0.75 -The glazed area should be increased in proportion to a reduction in the light transmission coefficient (e.g. sun protection glazing) or a reduction in the amount of light reaching the windows (e.g. in the vicinity of adjacent buildings) -Similarly, with the use of appropriate calculations and measurements, if the daylight factor in the room is 2%, it should be considered that the lighting conditions are adequate. When determining the daylight factor, the actual conditions should be taken into account, including the design of the windows, the light transmittance of the glazing, and the nature of the room and surroundings. - Technical guidelines for electric light 5.3.1.	- The permanent residence area should have an equivalent daylight access area, determined on the basis of an appropriate amount in m2 depending on the function of the room -this area is determined taking into account: structures and obstacles on the adjacent plot - window openings located at a distance of less than 2 m from the plot border are not taken into account - if the plot is located next to a public road, water body, green area, the distance principle mentioned above should be taken into account - principles and applications regarding ergonomics, visual comfort in relation to lighting - principles and applications - determination of daylight openings in the building - definition of the method	-The room intended for the stay of people should be provided with daylight, adapted to its purpose, shape and size, taking into account the conditions specified in § 13 and in the general provisions on health and safety at work. -In a room intended for people, the ratio of the window area, calculated in the light of the door frames, to the floor area should be at least 1: 8, while in another room where daylight is required for reasons of purpose - at least 1:12 -Rooms intended for people and for general traffic (communication) should be provided with artificial lighting according to the utility needs. - General artificial lighting of a room intended for permanent residence of people should ensure appropriate conditions for the use of its entire surface. 3. Lighting with artificial light of interconnected rooms intended for permanent stay of people and for general traffic (communication) should not show differences in intensity, causing glare at the passage between these rooms. -The distance of the building with rooms intended for people to stay from other objects should allow for natural lighting of these rooms (...)

The analysis of case studies demonstrated that the main factors influencing design decisions were:

- design idea / objectives to follow user/investor visual and comfort needs
- building regulations for a given country
- daylighting recommendations found in national building or lighting regulations.

The most noticeable daylight solutions integrated within the buildings design were:

- the use of double-glazed skylights and windows as the dominating architectural elements providing daylight,
- the automated control of daylight integrated with a design of the façade – shading panels, horizontal blinds

The factors that had a great influence on daylight provision on the chosen architectural shapes were the aesthetic choices and visual comfort for the potential users of the buildings. Additionally, in offices the building structures (the shape and forms) were also designed to comply with the restrictions regarding the overshadowing and limitations of an orientation, and the size of the building plots.

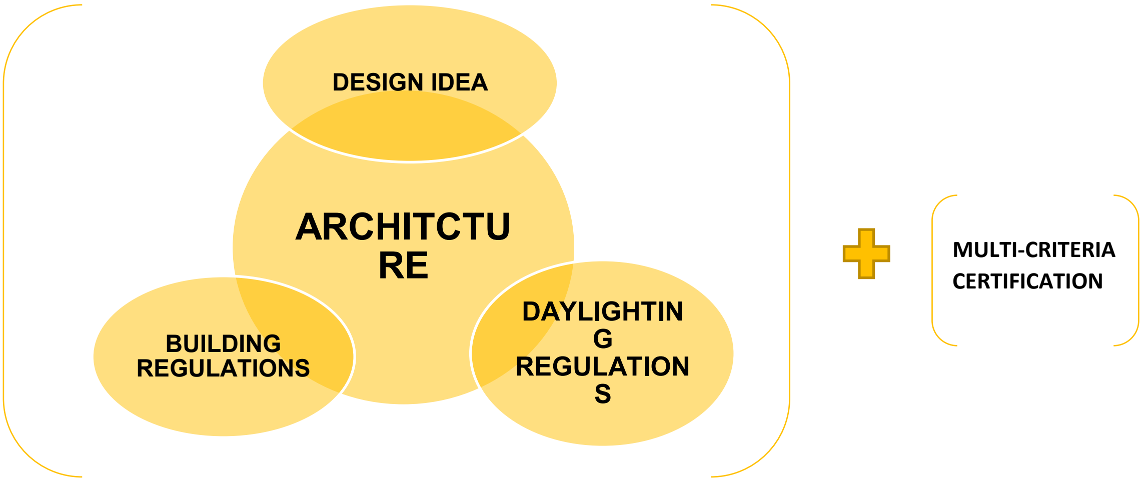


Figure 2. Noticed factors creating architecture.

Moreover, in both office cases it was stated that applying multi-criteria certifications (e.g. LEED, BREEAM) was an important factor. In terms of legal regulations and its impact on lighting solutions, the strong influence was noticed on the art gallery, opposite to office projects where the impact was very small.

We have found similarities regarding the conducted analysis in the studied projects. In all the projects there were carried out insolation analysis (sun path) and illumination analysis. Moreover, it is striking that in both office projects there were conducted analysis of the view out, which were not required in any binding regulations at the time.

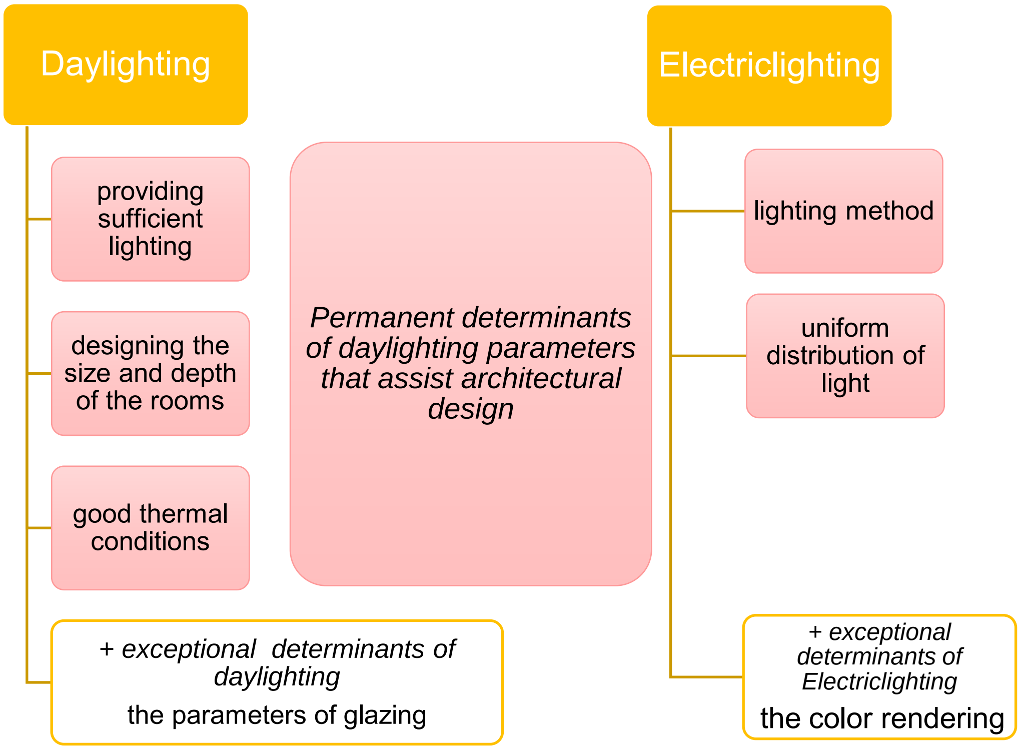


Figure 3. Key challenges of lighting design decisions

In all the projects the person who had made the design of the electric lighting was the lighting consultant from the external company. Moreover, in office buildings there was an architect involved in lighting design process as well. Regarding the situation where the architect was a member of the lighting design team, the aesthetic and the function of the lighting system were the most important responsibilities of an architect. In all the cases the key criteria in the aesthetic selection of the electric lighting were the shapes and colour of the lighting apertures, visual guidance, and orientation in the space.

The biggest challenges associated with the design of daylight in all the cases were to combine the following aspects: providing sufficient lighting, good thermal conditions and designing the size and depth of the rooms. In the art gallery, there were also challenges with the parameters of glazing, especially with the protection of art works against UV-radiation.

The biggest challenges connected to electric lighting in the three cases were different. In art gallery the issue was related to the reproduction of the colours of the paintings. In offices the following factors were important: uniform distribution of light and some aspects connected with lighting design like accent lighting of chosen objects and external lighting.

To conclude, all the actions taken in the projects regarding natural and electric light are strictly connected with: i) legal regulations that determine the lighting specifications, and ii) issues connected with rooms size (depth), energy consumption and user needs/comfort.

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Webpage of the project of the National Gallery in Dublin:

https://www.nationalgallery.ie/, https://www.hparc.com/work/national-gallery-of-ireland

2.7 Overall conclusions

There exist a large body of international lighting standards (CEN or ISO) and national mandatory codes, see table 2.1. In addition, there are non-mandatory certification documents (LEED, BREEM or WELL Building). Reports developed by CIE or national professional lighting bodies (SLL in the UK) are sources of even more detailed knowledge.

Following lighting codes and recommendations will not ensure good quality of design, but it usually help to prevent poor decisions, both in lighting and daylighting. The recommendations should be formulated clearly, the measures should be few but applicable to most situations, they should be easy to understand and simple to use.

The analysis of case studies demonstrated that the main factors influencing design decisions were i) design idea / objectives to follow user/investor visual and comfort needs, ii) building regulations for a given country and iii) daylighting recommendations found in national building or lighting regulations. In addition to mandatory national codes, also the non-mandatory, LEED or BREEM codes are being used.

This confirms again that codes are decisive for the architectural design and for the visual environment in buildings and cities. They are very much needed to avoid poor daylighting especially in dense urban areas.

The codes and recommendations are developed to ensure well-being and health of citizens. Still, most of the regulations do not include, nor refer to circadian metrics.

3 Literature review of building use

In this chapter the authors are asking what we can learn about use of buildings from the literature. The chapter starts with the discussion about the literature review methodology. The use of buildings is described for each of the following categories: offices, schools, university buildings, hospitals, commercial buildings and industry buildings.

3.1 Literature review methodology

To conduct the literature review two different methods were tried.

The first one was a qualitative method and comprised comprehensive sources of information (all databases). The main keywords were respectively: boundary conditions, behavior, occupancy, occupant and agent-based modeling. The initially proposed keyword "boundary conditions" and "agent-based modeling" gave no search results. Most useful keywords proved to be *occupancy, occupant* and *behavior* and their interrelations, se Figure 1.

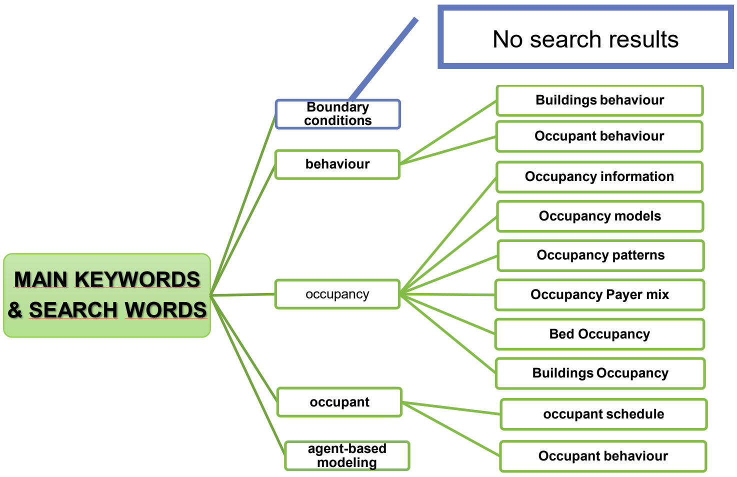

Fig. 3.1. Keywords used in the first literature review method.

The second method aimed at systematic review starting with the three keywords (energy, space use and light). It allowed to analyze more documents as the chosen keywords resulted in a larger number of articles. The search was then narrowed by adding new the keywords, see figure 3.2. However, due to time restrictions it was impossible to carry out such a literature review in all data bases; the use of this method was limited to the Scopus database.

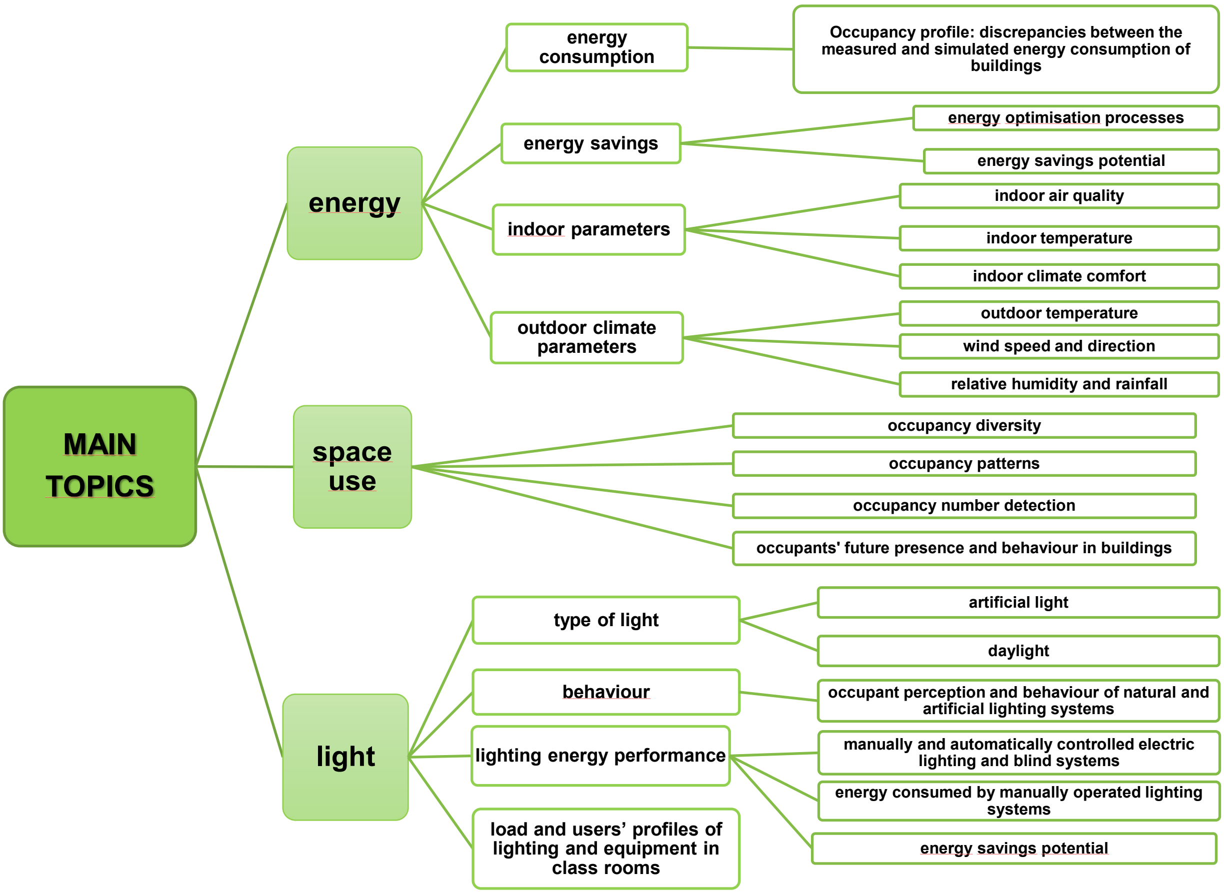

Fig. 3.2. Categories & Topics used in the second literature review method.

3.2 Offices

In offices, it is essential to take advantage of the natural light through a daylight responsive architecture, while providing the needed supplementary electric lighting through a good lighting design. In addition, contemporary office buildings commonly experience changes in occupancy patterns and needs due to changes in business practice and personal churns.

Despite standards provide recommendations to ensure a comfortable office environment, they do not consider that users and neighbouring users' requirements might differ due to their mood, activity, preference, and space usage. For these reasons, providing everyone with satisfying conditions becomes a challenge.

The literature review highlights that boundary conditions of office buildings use are linked with three main factors: energy aspects, space utilization and light conditions. Besides, each main factor is affected by different parameters, as showed in the figure below. Acting on these parameters/factors, designers can guarantee both users' comfort and energy saving.

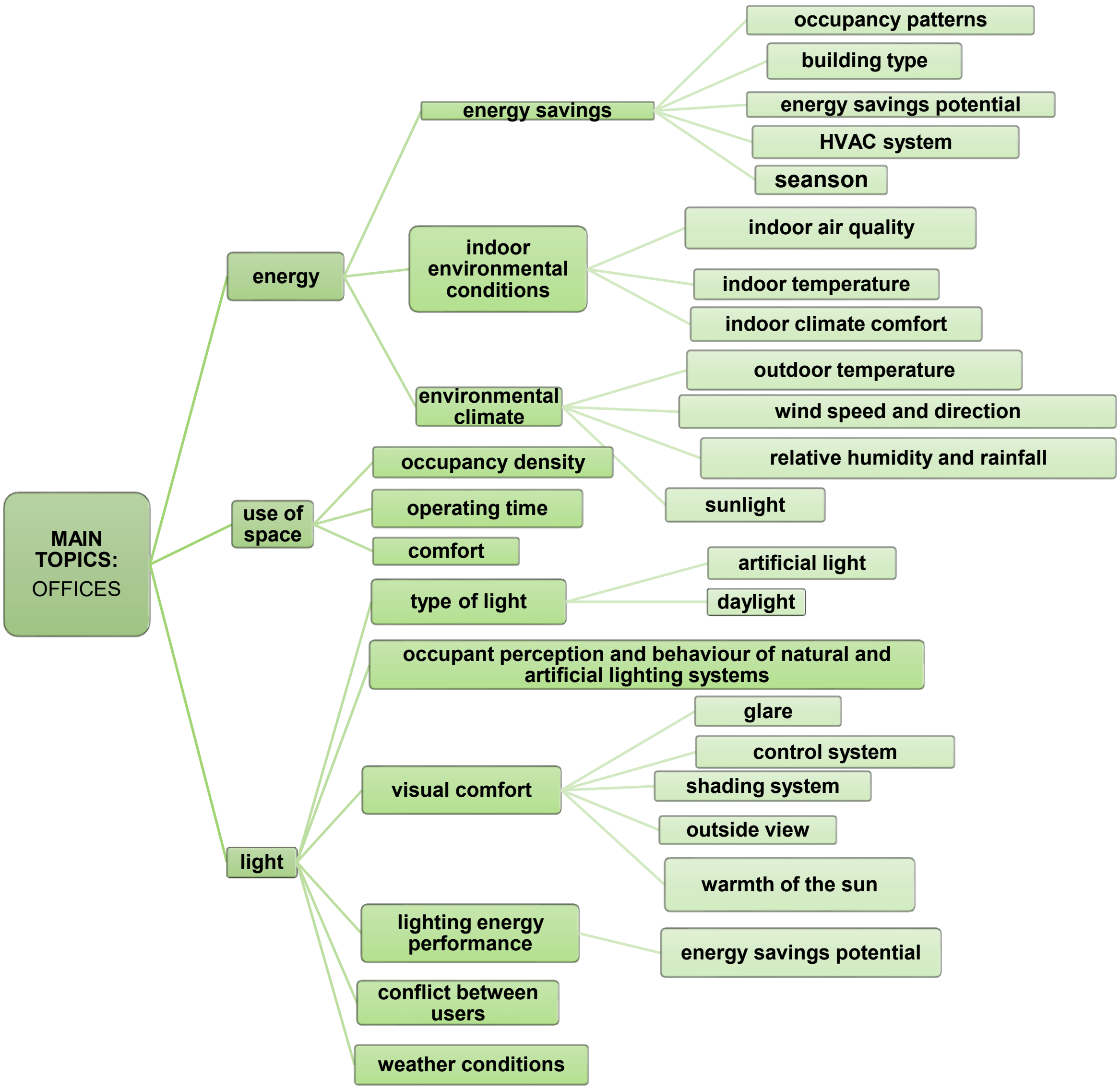

Fig. 3.3. Parameters that mainly affect boundary conditions of office buildings usage extract from the literature review.

3.2.1 Energy

Lighting is one of the largest energy users in artificially lit buildings, so daylighting strategies that potentially reduce the needs of electric lighting have been highlighted. However, they have not always materialized in practice, which is mainly due to the lack of understanding of occupant perception and behaviour of natural and electric lighting systems. Occupant behaviour is a crucial factor in determining lighting energy use in buildings.

Yun et al. [1] reported field survey results on illuminance distributions, occupancy and lighting use patterns, and resulting lighting energy demands. Four offices (office A, office B, office C and office D) of the college of engineering building at K University in the Republic of Korea were selected in [1]. The offices were located along double loaded corridors of the building. Each office had one external wall with double glazed window and there were internal blinds. The azimuth of the main facade is 4° for office A, 274° for office B, and 94° for offices C and D. The following table reports additional detail of the offices to investigate in [1].

Table 3.1. Details of the offices investigated by Yun et al. [1].

	Office A	**Office B**	**Office C**	**Office D**
Floor area (m^2)	41.25	31.00	41.25	41.25
Size of the main façade / window (m)	5.50 / 3.0	5.00 / 3.0	5.50 / 3.0	5.50 / 3.0
Azimuth of the main façade (°)	4	274	94	94
Lighting power density (W m^{-2})	10.47	9.29	10.47	10.47
Number of occupants	7	5	6	3
Type of occupants	Postgraduate students	Postgraduate students	Postgraduate students	Administrative employee

The results showed that there is no significant relationship between available daylight and the use of lighting by occupants in the investigated offices. The lighting use patterns are significantly related to the occupancy patterns of investigated offices and there is a strong tendency of turning on lighting on occupants' first arrival in the morning and of keeping the lighting on. In addition, their analysis showed that there are large potentials in terms of energy savings by the utilization of daylight. In particular, careful lighting control in relation to indoor daylight levels can save lighting energy use by up to 30%.

Oldewurtel et al. [2] investigates the potential of using occupancy information to realize a more energy efficient building climate control. The study focuses on Swiss office buildings equipped with Integrated Room Auto-mation (IRA), i.e. the integrated control of Heating, Ventilation, Air Conditioning (HVAC) as well as lighting and blind positioning of a building zone or room. To evaluate the energy savings potential, different types of occupancy information are used in a Model Predictive Control (MPC) framework, which is well-suited for this study due to its ability to readily include occupancy information in the control. An MPC controller, which controls the building based on a standard fixed occupancy schedule, is used as a benchmark. The energy use of this benchmark is compared with three other control strategies: first, the same MPC controller which uses the same schedule for control as the benchmark, but turns off the lighting in case of (an instantaneous measurement of) vacancy; second, the same MPC controller which uses the same schedule as the benchmark for control, but turns off lighting and ventilation in case of (an instantaneous measurement of) vacancy; and third, the same MPC controller as the benchmark but using a perfect prediction about the upcoming occupancy. The comparison is carried out for different buildings, HVAC systems, seasons and occupancy patterns in order to determine their influence on the energy savings potential. It was found that energy savings are increasing with respect to increasing vacancy and decreasing occupancy days. The simulations with homogeneous occupancy showed a savings potential of up to 34% for the case of average vacancy and occupancy intervals of 5 and 10 days, respectively. In the simulations with alternating occupancy, the savings are in the range of 50% of the savings with homogeneous occupancy. Taking into account occupancy information in building control has a significant energy savings potential. However, a large part of this potential can already be captured by taking into account instantaneous occupancy information.

3.2.2 Space use: occupancy detection

The definition of the number of people that occupy a particular space and for what duration is difficult to characterize because human behavior is considered stochastic in nature, however, occupants do not arrive and leave at the same time every day and their locations within the building varies throughout the day and this distribution can be valuable information when evaluating demand control strategies. In addition, contemporary office buildings commonly experience changes in occupancy patterns and needs due to changes in business practice and personal churns. Therefore, detection of occupant presence has been used extensively in-built environments for applications such as demand-controlled ventilation and security, and occupancy profiles are widely used in building simulations [3–9]. In particular, Lam et al. [3] presented the results of the acquisitions from deploying a large-scale sensor network in a test-bed open office environment. Three separate sensor network system were installed: (i) a wired sensors gas detection sensor network (CO_2, CO, TVOC, outside temperature, dew point and PM 2.5); (ii) a wireless ambient-sensing network (lighting, temperature, relative humidity, motion and acoustics) and (iii) an independent CO_2 sensor network. The acquired data were postprocessing and the most relevant features were then used in conjunction with three machine learning methods (Support Vector Machines (SVM), Neural Networks (NN) and Hidden Markov Models (HMM)) for the estimation of occupancy numbers for a typical daily schedule. Their results [3] showed that, due to the characteristics of the open office plan, CO_2 and acoustic parameters have the largest correlation with the number of occupants in the space. A Hidden Markov approach to occupancy detection results in estimation accuracy were similar to that of a Neural Network approach. However, the HMM model more realistically described an occupancy presence profile due to its ability to discount sudden brief changes in occupancy levels as well as maintain a constant level during static occupancy periods. Both the daily and weekly results showed that the HMM achieved reasonable tracking of an actual occupancy profile. Duarte et al. [4] provided new deterministic occupancy diversity factors for common commercial office building space types using data (23-month dataset) from a large multi-tenant office. In particular, occupancy sensor data were collected from a 195,000-ft2, 11-story speculative commercial office building located in Boise, Idaho. A total of 629 occupancy sensors were located throughout the building comprising private and open plan offices, conference rooms, lobbies, hallways, reception areas, and supporting spaces such as mechanical and electrical rooms. They showed that there are statistically significant differences to suggest four unique diversity factors for day of the week (Monday, Tuesday–Thursday, Friday, and three unique diversity factors for month of the year, and for three holiday groups. In addition, this research [4] has been shown that measured occupancy data have a significantly lower diversity factor than the ASHRAE 90.1 2004 recommended practice. Measured data shows as much as a 46% reduction in average day profile peaks for private office occupancy and about a 12% reduction for open plan office spaces when compared to the ASHRAE model. Mahdavi and Tahmasebi [5] evaluated the predictive potential of two existing probabilistic occupancy models (one is the Lightswitch-2002 model [6] and anther one is that developed Page et al. [7]) comparing their performance with a simple original non-probabilistic model of occupants' presence, which was developed to be deployed in simulation-powered predictive building systems control [8]. These models were used to generate predictions of daily occupancy profiles using the past monitoring occupancy data obtained from eight (individually monitored) workplaces in an office area in a building of the Vienna University of Technology. The outcome revealed modest levels of predictive performance by all models, especially the probabilistic ones. In this context, Mahdavi and Tahmasebi suggest that an evaluative approach similar to the one we suggested and applied in their research – albeit on a larger scale – would be critical for future studies that intend to evaluate and improve the predictive potential of occupancy models.

According to [9], occupancy profile is one of the driving factors behind discrepancies between the measured and simulated energy consumption of buildings. The frequencies of occupants leaving their offices and the corresponding durations of absences have a significant impact on energy use and the operational controls of buildings. Starting from the measured lighting-switch data in five-minute intervals, for a total of 200 open-plan (cubicle) offices, subdivided into three floors of an office building, the profile of presence hours, the number of daily absences and the absence duration were deduced. Each cubicle had a single, workstation-specific suspended fixture with a built-in occupancy sensor. The sensor detected occupant movement and controlled the lighting switch for each cubicle. The light was activated (switched on) if the cubicle was occupied, and deactivated (switched off) if unoccupied. The collected patterns were classified into five patterns according to occupancy variation, appearance duration in the cubicle, and occupant personality: Pattern 1 (single-square curve), Pattern 2 (one-valley curve), Pattern 3 (two-valley curve), Pattern 4 (variable curve), and Pattern 5 (flat curve). The study observed that occupancy patterns were influenced slightly by the location of the cubicle. Longer occupancy periods occurred in more isolated cubicles that had more privacy, or cubicles that were near windows. However, the job category may have more impact on occupancy patterns than the location of the cubicle. Statistical results show that the most common occupancy among all occupants is Pattern 2. The most typical numbers of daily absences for Patterns 1 to 4 are 1, 4, 5, and 9, respectively. Additionally, the absence durations for each absence are mostly from 10 to 29 minutes for all occupancy patterns. The number of absences decreases with the long absence duration for all patterns.

3.2.3 Light

3.2.3.1 Electric lighting

Despenic et al. [10] proposes a first method for modelling lighting preference profiles of users based on their control behaviour and preference information. The primary objective of the paper was to compare the subjective experience of participants when they do not have lighting control, the “no control” conditions, with their experience when controls are provided, the “control” conditions. In this respect, the subjective experience in terms of satisfaction with lighting conditions, preference for “no control” or “control” and the experience of conflict are compared. Since personal control in an open office can be offered in various ways, the second objective was to explore and compare different design choices of offering personal control with respect to user satisfaction. Five experimental conditions are investigated: two without personal control and three with personal control in which the users can dim lighting level of the 6 control zones between 1% and 100%. The authors show that users can be profiled based on their light preference and control behaviour in the following ways: activeness, tolerance, dominance and lighting preferences. Based on lighting preference profiles of the users who occupied them and the zone luminaire output, each control zone can be classified into three cases. By knowing how a control zone is classified, the satisfaction of the individual users within a particular zone can be automatically evaluated and conflict between the users can be predicted. Research results show that users satisfaction in an open office environment mainly depends on the lighting preference profiles of office users, the probability of conflict between the users in the same control zone as well as the lighting control strategy.

3.2.3.2 Windows and shading systems use

As human well-being and productivity are strongly affected by the built environment, providing comfortable room conditions is a vital part of designing office buildings. Thermal comfort can surely be achieved with enhanced ventilation systems or air conditioning. However, in moderate climates a passive cooling concept using natural effects such as night ventilation with manually controlled windows in combination with an exhaust fan and high thermal inertia could, in principle, provide the same level of comfort with a substantially lower environmental impact. According to the literature, the actions on windows are correlated with some parameters as the respondent’s gender, the outdoor temperature, the perceived illumination, air quality and noise levels had a statistically significant impact on ‘‘perceived’’ window opening behaviour [11].

Measurements performed in an office building, in which six south-oriented offices are occupied by two persons, which can both individually access their window, while eight south-oriented offices accommodate single occupant able to act on the two windows, highlighted that:

- actions on windows most commonly occur when occupants arrive or leave their offices. A possible explanation is that during this time occupants may perceive considerable differences in thermal and/or olfactory stimuli compared to their previous (possibly external) environment and their offices. These differences may be exacerbated by the lack of adaptive actions while the occupant was not present. For offices with two occupants, a slightly greater proportion of openings during occupancy can be observed,
- both internal and external temperatures are linked with actions on windows. A clearly increasing proportion of windows open may be observed for internal temperature rising from 20 °C to 28 °C, and a similar phenomenon occurs with external temperature, for which the maximum proportion being reached around 26 °C, above which a decrease is clearly significant,

- a less sharp decrease in the proportion of windows open is visible when outdoor humidity rises,
- mean wind speed increase is linked with a decreased proportion of open windows for wind velocity greater than 2 m/s,
- no particular variation is observed with wind direction,
- no clear pattern is noticed with respect to rainfall.

Regarding the variability between occupants and personal patterns related to actions on windows, it was noted that some occupants used their windows more frequently than do others. In addition, no obvious difference in behaviour related to total opening duration is distinguishable between offices with one or two occupants. In this latter case, one possibility is to assume that occupants act independently and the ''activity'' in an office is aligned to that of the most active (or assertive) of the occupants [11].

The percentages of open windows and frequency with which windows are opened or closed strongly correlate with the season. In summer, the percentage of open windows is much higher than in winter. A sudden increase and decrease of the percentage of open windows is found in spring and autumn, indicating a change in the user behaviour presumably resulting from the first cold/warm day during the year As the highest percentage of open windows is found in summer, this results in a small number of window openings and closings. In winter, the length of time when a window is open is short, but the percentage of open windows is small. The highest frequency in changing the window-opening status is observed in spring and autumn probably because weather conditions are changing sharply. When reaching a certain temperature, the measured percentage of open windows increases strongly until a maximum is reached. However, 100 percent, as found in previous studies, is never reached, indicating that some windows are rarely, if ever, opened. The percentage of open small windows and tilted-open large windows varies only slightly between day and night, whereas completely open windows show big differences. At night no windows are completely open. Analysis of the user behaviour during the course of a day shows that windows are opened and closed more frequently in the morning, at lunchtime and in the evening. Analysing the arrival and departure of the occupant in detail reveals that most window openings and closings take place at arrival. Departure is the second most likely time to manipulate window status [12].

Regarding the use of shading systems, Alam and Shari [13] present the occupants' behaviour towards the use of window blinds in a green office building in Malaysia. The research shows that the change of window blind occlusion value is statistically significant in relation to the building orientations and floor levels only. There was no significant relationship between the blind occlusion index and the sky conditions this time. The interaction between orientations and floor levels are significant for the average blind occlusion index. However, interestingly, the Pearson Correlation test revealed that there was only one significant correlation which was between the window blind occlusions and the building orientations. Floor levels, sky conditions and time of the day did not obtain significant values. The questionnaire survey found that during the period of survey, majority of the participants rarely adjusted their window blinds (81.1%), whereas 11.1% of them said they operated their window blinds at least once in a day, and 7.8% occasionally operated their window blinds. This result indicates that the occupants' seating positions did not influence their blind operations. In addition, the investigation exhibits that the top five reasons cited by the respondents were "excessive daylight or glare", "to have the outside view", "to increase daylight level", "to reduce heat gain", and "to feel the warmth of the sun".

3.2.3.3 Daylighting and electric lighting interrelationship

The energy performance of automated controls is relatively straightforward to model as it is based on deterministic correlations between physical quantities like the illuminance at a photocell and the status of an electric lighting system. The more challenging task is to model a conventional one-level manual switch, which constitutes the most common practice and should function as a reference system, relative to which energy savings of automated lighting controls should be expressed [6].

Regarding the control of the lighting system, it is possible to underline that:

- manual lighting control mainly coincides with the occupant's arrival at or departure from the workplace. Some individuals always activate their lighting throughout the whole working day independently of prevailing daylight levels (behavior user does not consider daylight). Others only switch on their electric lighting when indoor illuminance levels due to daylight are low (user considers daylight) and the switch-on probability for electric lighting tends to be correlated to minimum indoor illuminance levels at the work plane upon arrival [6,14];

- people occasionally switched the lights on during the period of occupation. Again the criterion may have been the room or task darkness. The relative infrequency of switch-on's during periods of occupation may have been due to a combination of several factors such as: (a) a reluctance to take action which might disturb or distract other occupants in the space; (b) a disinclination to interrupt work in order to move to the light switch (which for most of the installations considered in this paper was situated away from the work stations, by the door); (c) the adaptation of the eye to gradually decreasing light levels; (d) the small number of occasions on which the daylight fell substantially below its start of occupation level [14]. The work plane illuminance values of 250 lux represent the minimum value at which the subjects in a laboratory study tended to reset their electric lighting levels that were slowly falling over time [6];
- in multi-person offices, people generally switched the lights off in a room at times when it became completely empty [14];
- a factor of primary importance in considering light switching behaviour is the nature of occupation of a space [14];
- the length of absence from the workplace strongly correlates with the probability that the electric lighting is manually switched off. It has been found that the presence of automated lighting controls influences the behavior of some people. People in private offices with occupancy control were found to be less likely to turn off their lights upon temporary departure than people without sensors. Similarly, switch-off probabilities were found to be lower for a dimmed, purely indirect lighting system for an undimmed system [6].

It is of more interest also to consider the daylight levels at which people actually switched on the lights, and compare them with daylight levels for instances when people chose not to switch on the lighting. Different behaviours can be observed for the intermittently and continuously occupied spaces. In intermittently occupied spaces (classroom), people switch lights on and off throughout the day and the probability of switching on was closely related to the daylight level. Hence the overall use of artificial lighting fell steadily with increasing daylight illuminance and, in fact, was completely absent at the highest levels. Artificial lighting was used for less than 50% of the occupied time that the internal daylight level, over the whole of the working plane, exceeded 300 lux, and for none of the time that it exceeded 1200 lux. In continuously occupied spaces (the multi-person offices), because people rarely switched lights off during the day, they were often in use over areas where the internal daylight level exceeded 1000 lux [14].

With regards to blind control, occupants avoid the presence of direct sunlight at their workplace by activating their shading device, i.e. lowering their blinds to block direct sunlight. While this closing criteria for blinds is well established, it remains unclear whether occupants re-open their blinds on a daily, weekly or even seasonal basis. As for electric lighting, there is a wide individual spread: i) blinds were left untouched in single offices for weeks and months or ii) some occupants tended to retract their blinds daily at departure or in the morning upon arrival [6].

Investigations performed for private or two-person office highlight that energy savings largely depend on the occupancy profiles at the workplace and lighting control strategy. If the lighting system can only be activated manually through a single on/off switch located near the entrance and switched off either manually by the user or automatically by the occupancy sensor once the workplace has been deserted for more than 10 min, it allows an average energy saving of about 20%. While, an occupancy control that always activates the electric lighting during occupancy prevents users from working by daylight alone. As a consequence, energy savings, that a considerable proportion of occupants would otherwise recuperate with simple manual control, are lost through such a control system. This type of occupancy control should be restricted to aisles, lavatories and other unassigned areas where occupants do not tend to use manual controls. A photocell-controlled lighting system has an enormous savings potential (59% for direct dimmed). Anyway, these savings can reduce to virtually nothing if the lighting is not regularly switched off outside of regular working hours [6].

Gentile et al. [15] evaluate both the actual energy performance and occupants' satisfaction of some common efficient lighting control systems (LCSs) in individual office rooms, where the conditions are as close as possible to real life settings. Four LCSs were chosen among the ones commonly proposed by practitioners in the case of single occupant offices: presence detection PSD (occupancy-linked system with presence detection), absence detection ASD (manual switch at the door combined with absence detection), daylight harvesting with absence detection (DHS) and LED task lamp. The field study was carried out in four identical single occupant office rooms located in the periphery of a large building of Lund University's Campus (LTH), Lund, Sweden (55°420N, 13°120E). The rooms selected for the study were all facing West as for this orientation, during the spring, direct sunrays tend to penetrate the offices only during late afternoon hours. The results indicate that the manual switch with absence detector was greatly appreciated and it accomplished good energy performances (75% savings compared to the presence detector). The daylight-linked LCS achieved only slightly higher savings (79%), due to relatively high standby losses. The desk lamp achieved 97% savings, but the lighting conditions were considered unacceptable by the office workers. In general, the participants in this study perceived all automatic controls as stressful. In the case of small individual or double-occupant offices, the most profitable solution appears to be a classic manual switch combined with an absence detector. This solution guarantees good energy savings and it is highly appreciated by the occupants, in addition to being rather simple to install and robust in the maintenance and functioning.

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3.3 Schools

The breadth of the term education buildings embraces different schools' types: day care centre, kindergarten, elementary, primary and secondary school buildings. These offer different education levels and reflect different occupation densities, time-table occupation and therefore different energy consumptions. Schools represent an important building typology because of their level of energy consumption but also through their role in the education of young people.

The literature review shows that boundary conditions of schools/kindergartens and day care centers buildings use are associated with space utilization, energy aspects, light, acoustic and thermal conditions. These factors determine the conditions of comfort and are important issues to be considered when developing the architectural design of educational environments. Many parameters impact the proper functioning of a school building operation and affect both users' comfort and energy consumption.

The first boundary condition of schools/kindergartens and day care centres is the use of space. The space utilization can be linked with design strategies, occupancy densities, hours of use, comfort or positive distractions. The quality of both outdoor environments (playground, activities, green space, etc) and windows views (sky, weather, natural/urban landscape, etc) constitutes positive distractions.

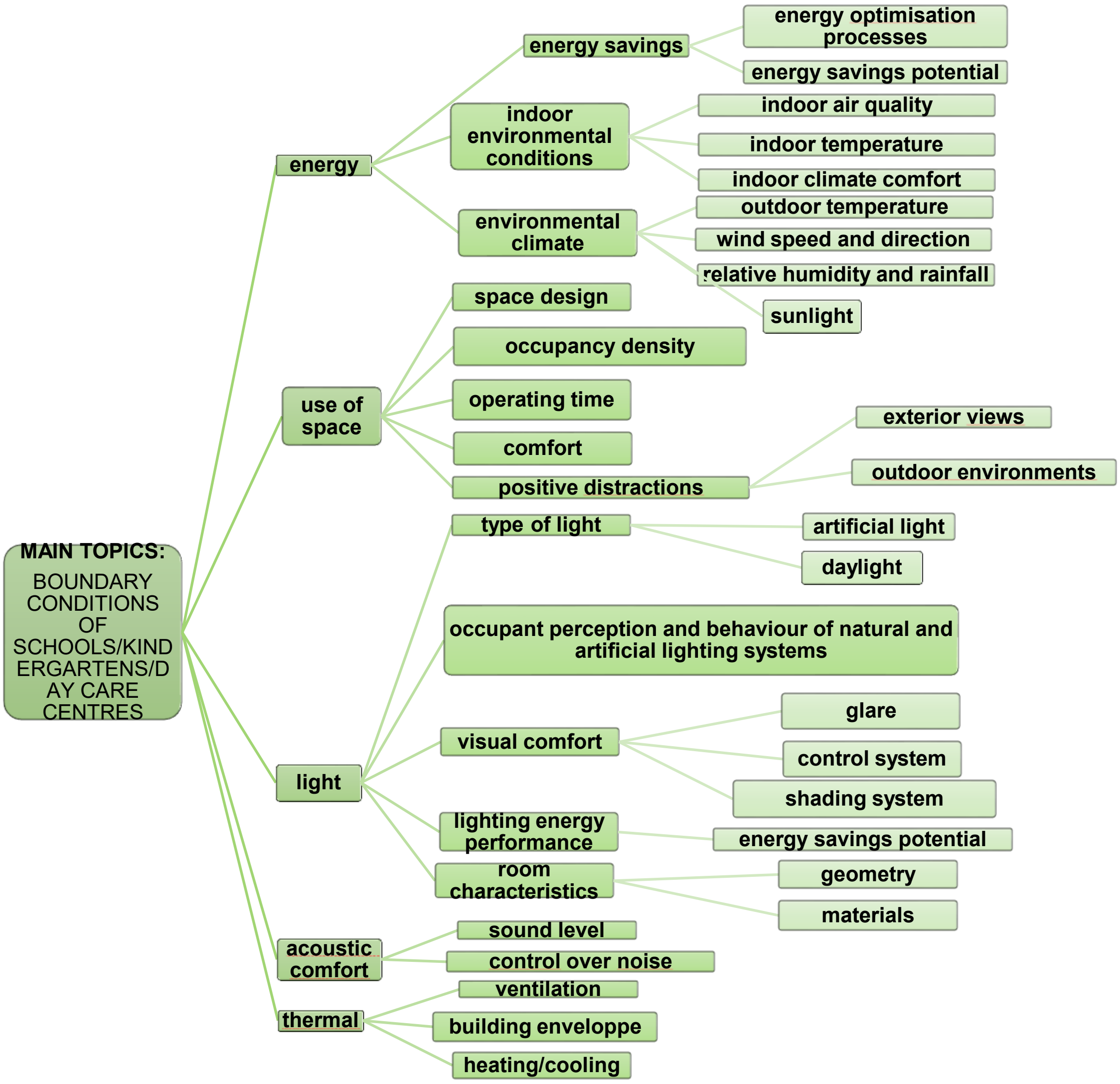

Fig. 3.4. Keywords used in the literature review for school/kindergarten/day care buildings.

Secondly, the occupancy behaviour in primary schools, kindergartens and day care centres is influenced by the energy aspect, which is determined by indoor as well as outdoor climate environment and is also related with energy savings. Indoor parameters are air quality, temperature and thermal comfort. Outdoor parameters are solar radiation, exterior temperature, wind speed and direction, relative humidity and rainfall. Energy savings are related to the energy optimisation process and the energy savings potential.

Third, light can affect the behaviour of occupants in schools, kindergartens and day care centres. Electrical lighting, daylight and how users perceive and react to these are parameters to consider. More specifically, concerning the electric lighting, various features affect the occupancy. First, the luminaires must be arranged as to obtain a uniform distribution of the lighting, Then, the type of the light source needs to be chosen with adequates correlated color temperature as well as Colour Rendering Index. Finally, the lighting system must be designed to avoid flickering (ballasts). Besides, visual comfort is impacted by glare, light quantity and uniformity which also involve control and shading systems. The room characteristics (geometry and material properties) influence the lighting aspect as well. Finally, the lighting in schools' buildings represents a potential in energy savings.

Acoustic comfort can influence the occupancy behaviour in schools too. Acoustics can be related to the sound level (environment) and how to control the noise.

Thermal comfort influenced by ventilation, heating/cooling systems and the thermal properties of the building envelope is also an aspect impacting the occupancy behaviour in educational buildings.

3.3.1 User-centred design

Several studies have highlighted the association between physical environment, human wellbeing, health and performance. Thus, a user-centred design of educational buildings (day care centres, kindergartens, primary and secondary schools) could be considered. In the literature, the impact of indoor air quality and users' preferences/perceptions (pupils and teachers) are the main topics. However, most of the time, studies are specific to a location and therefore to a particular context.

In the UK, Barret et al. (2015) realized assessments of 153 classrooms in 27 schools in order to identify the impact of the physical classroom parameters on the academic progress of the 3766 pupils who occupied each of those specific spaces. This study confirms the importance of naturalness, individuality and stimulation ways as a vehicle to organise and study the full range of sensory impacts experienced by an individual occupying a given space, see Table 3. In this study, the naturalness design principle accounts for approximatively 50% of the impact on learning, with the other two accounting for roughly a quarter each. Within this structure, seven key design parameters have been identified: Light, Temperature, Air Quality, Ownership, Flexibility, Complexity and Colour. Together they account for 16% of the variation in pupils' academic progress achieved; the Light parameter has the strongest impact and accounts for 21% of all parameters.

Table 3.2: The main classroom characteristics that support the improvement of pupils' learning

Design principle	Design parameter	Good classroom features
Naturalness	Light	- Classroom towards the east and west can receive abundant daylight and have a low risk of glare. - Oversize glazing must be avoided. - Electrical lighting with higher quality can provide a better visual environment.
	Temperature	- Classroom receives little sun heat or has adequate external shading devices. - Radiator with a thermostat in each room gives pupils more opportunities to adapt themselves to the thermal environment.
	Air quality	- Large room volume with big window opening size at different heights can provide ventilation options for varying conditions.
Individualisation	Ownership	- Classroom with distinct design characteristics, personalized display and high-quality chairs and desks
	Flexibility	- Larger, simpler areas for older children. - More varied plan shapes for younger pupils.
Stimulation	Complexity	- Room layout, ceiling and display.
	Colour	- White walls with a feature wall. - Bright colour on furniture and display.

Li and Sullivan (2016)showed that classrooms view of natural scenes may have more impact on the children's attention recovery from stress than daylight. Vásquez, Felippe et al. (2019). performed a study on kindergartens in Brazil to define the children's preferences about luminous environments and quality of the outside view. They found that preschool classrooms with more natural views could be more stimulating for younger children, while classrooms with window views of built elements could be more stimulating for older children.

During the design process, energy assessment calculations may be used, and the results should be as accurate as possible to avoid inappropriate decision and inefficient optimisation measures. For this purpose, Wauman, Saelens et al. (2015)studied Flemish schools to improve accuracy of the energy calculations, especially those related to the implementation of user- and activity-related boundary conditions. Values for schedules, control systems, use of artificial lighting and equipment, ventilations characteristics and internal heat gains are determined. Thus, for schools, kindergartens and day care centres buildings, operational schedules are well predictable. Indeed, opening hours during the year are mostly similar and holidays are fixed. However, the occupation timetables can be different regarding school types. Another study on Finnish schools and day care centres (Sekki, Airaksinen et al. 2015) demonstrated that on one hand, day care centre buildings have similar user profiles, with only minor variation between these. On the other hand, schools have clearly identifiable user profiles but the variation between the buildings is greater. Moreover, in one building, although opening hours are the same, small differentiations can be observed due to breaks and outdoor meetings/classes. It results in a change in the control of the HVAC system, lighting and equipment. Additionally, they might lead to a different occupancy and thus possibly affect both internal heat gains and ventilation rates. Concerning indoor temperatures, results are showing that secondary schools have a slightly more stable but lower temperature regime. Nursery schools which welcome young children (<6 years old) request slightly higher indoor temperatures.

Table shows operational schedules depending on the school type for different countries. There are fewer annual operating hours on average for kindergartens and primary schools, but extra activities are not considered. Day care centres offer more extended operational hours matching parents' work hours.

Table 3.3: Operational schedules depending on the school type and the country

School type	Country	Operational schedule	Comments
Day care centre (Sekki, Airaksinen et al. 2015)	Finland (Espoo)	±11h per day: 6.30am to 5.30pm, Monday to Friday ±2000 annual operating hours on average	Some are in use 24h or the service is extended (16h per day); Sometimes in use during summer; Activities on weekends / in the evenings (from 5pm to 9pm)
Primary schools (Sekki, Airaksinen et al. 2015)	Finland (Espoo)	5h30 per weekday, from 8.30am to 2pm ±1000 annual operating hours on average	Activities on weekends/in the evenings (from 4pm to 9pm)
Preschool	Finland (Helsinki)	4h per weekday ±760 annual operating hours on average	Day care service can be provided complementary to preschool education
Primary schools (Mysen, Berntsen et al. 2005)	Norway	From 8.30am to 1.30 or 2.30pm, Monday to Friday ±1100 annual operating hours on average	Classrooms are used daily for 4 hours for normal school activities. After school activities.
Primary schools (Wauman, Saelens et al. 2015)	Belgium (Flanders)	From 8.30am to 4pm, Monday to Friday ±1200 annual operating hours on average	Wednesday afternoon is free; After school activities.
Kindergartens	Belgium	From 8.30am to 3.30pm, Monday to Friday ±1100 annual operating hours on average	Wednesday afternoon is free; After school activities.
Primary schools/ Kindergartens	France	From 8.30am to 4.30pm, Monday to Friday ±1400 annual operating hours on average	Wednesday afternoon is free; After school activities. Classrooms are used 24h per week.
Day care centre	France	In most cases, from 7am to 7pm ±3000 annual operating hours on average	Schedules vary from centre to centre.
Primary schools/ Kindergartens (Aguilar-Jiménez, Velázquez-Limón et al. 2020)	Mexico	From 8am to 3pm, Monday to Friday ±1400 annual operating hours on average	

3.3.2 The influence of indoor environmental quality in primary schools and kindergartens buildings

Comfort and occupant's efficiency in indoor environments are influenced by Indoor Environmental Quality (IEQ): adequate lighting, space occupancy for everyone, etc. Children spend about 30% of their time at school, therefore their future development may be impacted by the indoor environment. Indeed, children spend up to 5–8 h a day between the ages of 5–18 in educational buildings (OECD, 2012). It is essential therefore that these buildings provide the best possible infrastructure, not only in terms of teaching but also with respect to climatic conditions within the classrooms. Poor IEQ impacts both adults and children, but the younger ones are arguably of greater concern due to their more fragile immune systems. Many studies show that poor IEQ can cause physical discomfort (fatigue) and influence pupils' performance, behaviour and productivity. Regarding the importance of IEQ in schools, many studies (Montazami, Wilson et al. 2012, Puteh, Adnan et al. 2014, Salleh, Kamaruzzaman et al. 2015) have identified building characteristics that affect the users' health and performance. These include indoor air quality, temperature, visual aspects, acoustics, daylight and artificial lighting, ergonomics and space.

A quantitative study on several kindergartens in Malaysia (Salleh, Kamaruzzaman et al. 2015) identified indoor air quality (IAQ) as the most significant indoor environmental aspect. In the classroom it is understood that poor IAQ could have a negative impact on children's learning. It is therefore of critical importance to minimize the concentration of pollution in classrooms, especially at schools located near roadways. Daylighting is also an important IEQ factor in occupants' preference for their workplace. Noise from the outside and even sometimes from other classrooms is also a criterion about which users complain.

Studies (Heschong, Wright et al. 2002) on the properties of light sources have found that their photometric characteristics had an influence on cortisol production and concentration as well as academic performance of children aged 8-11 years.

Moreover, issues related to indoor environmental quality become more complicated when dealing with students who have been diagnosed with mental health disorders and need special attention and treatment. A study (Vilcekova, Meciarova et al. 2017), carried out in classrooms in a school dedicated to students having disorders like ADHD in Slovak Republic, evaluated the environmental comfort for both students and teachers. The survey shows that acoustic discomfort raises the most concern for the occupants, but they also experienced varying indoor air temperature, poor air quality, unpleasant smell as well as strong or very poor lighting. Figure 3 illustrates IEQ concerns respectively for students and staff.

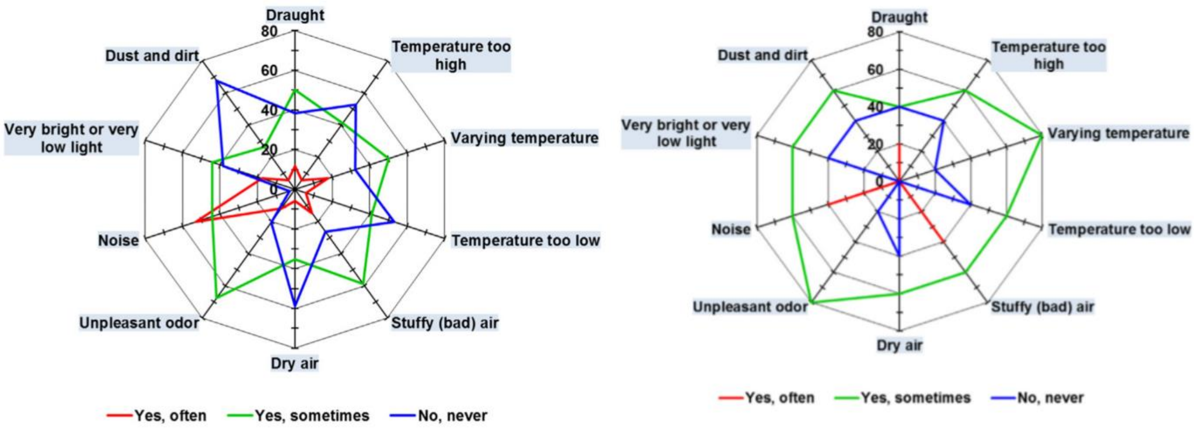

Figure 3: General evaluation and responses respectively for students and staff for IEQ problems in classrooms

3.3.3 Lighting energy saving potential and comfort perception in classrooms

In schools, the sectors with the largest energy consumptions are space heating, lighting, cooling and finally ventilation (Dias Pereira, Raimondo et al. 2014). Figure represents the average energy scenario for schools in the USA. Light use has been consistently highlighted as a crucial factor in the performance of school buildings, for two main reasons: visual comfort is connected to student performance (Mumovic, Palmer et al. 2009);and artificial light is the main source of energy consumption in schools located in moderate climate areas (Almeida, Ramos et al. 2016).In terms of lighting, classrooms are the most significant consumers: almost 50% of the total energy in a school building.

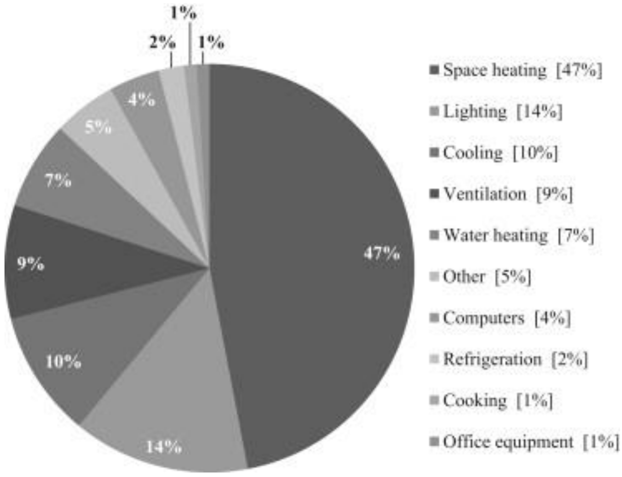

Figure 3.6: Average energy use profile of schools in USA

Daylighting affects both energy consumption and well-being. Significant improvements in the light qualities of school buildings are necessary in order to improve visual comfort, energy efficiency and, ultimately, environmental sustainability. Thus, many studies show that energy savings can be achieved when daylight is well exploited. Delvaeye, Ryckaert et al. (2016) documented the annual energy savings of three different daylight control systems in a school, ranging from 18% to 46%. A study (Bernardo, Antunes et al. 2017) Portugal estimated a 11.2% reduction in energy consumption thanks to daylight harvesting. Yu, Su et al. (2014) performed calculations with the aid of RELUX software to conclude that the annual energy savings from daylight exploitation range from 40% to 46% for a new educational building in the UK.

Energy use is closely linked to their operational and space utilisation characteristics and the behaviour of their occupants. Daylight control systems, which automatically adjust the artificial light levels depending on the daylight penetration, can help saving energy. However, it depends on several building and system parameters, climate conditions, occupant behaviour as well as type and commissioning of the daylight control system.

Resulting from a year-long post observational study conducted at schools, Lourenço, Pinheiro et al. (2019) explain the current situation regarding light-use management in Portuguese secondary school buildings. They are adopting the point of view of their facilities, user behaviours and their impact on energy use patterns. Both natural and artificial light-use patterns are considered. Although the classroom is still the functional space where students and teachers spend most of their time, new educational paradigms also require that attention is paid to other functional spaces where informal learning takes place. Results show that besides users' visual comfort parameters and functional needs, light use in schools is also strongly influenced by organizational habits. The study led to the development of more environmentally sustainable design and management strategies in school buildings. Results also showed that improvements in the design and management of circulation areas could lead to significant reductions in artificial light (and energy) use. By adopting a more efficient light management in privileging natural light, energy use could be reduced. Such strategies imply an integrated approach to natural and artificial light use. Thus, design strategies should define how to design windows to achieve the required standards of uniformity or to promote equal conditions among students, as far as the use of natural light is concerned.

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3.4 University buildings

University is an educational institution, but facilities composing a campus have a wide variety of building types and uses such as administrative buildings and spaces, classrooms, experimental rooms, meeting rooms, studios, libraries, auditoriums, gymnasiums, shops, cafés and restaurants, dormitories, hospitals/clinics and so on. It is no exaggeration to say that a university makes a town or a small city. Its impacts on energy use and greenhouse gas emission are huge and a vital concern not only to the administrator of the university but also to the relevant local authority. Besides, according to changes in teaching and learning methods, various kinds of technical equipment are adopted in academic buildings.

The literature review shows that boundary conditions of university building use are associated with energy aspects, thermal comfort, heating, cooling, air conditioning, ventilation and lighting. These factors are fundamental to the building environment and commonly important to all building types. University buildings need to meet requirements for net-zero-energy/zero-energy buildings (nZEBs/ZEBs) and green renovation. IEA Global Status Reports (2018, 2019) show recent increase in space cooling energy use in contrast to decrease in space heating energy use in the buildings and construction sector. Many of recent research papers are directed to university buildings in hot climates, where thermal comfort comes in first.

Gou et al. (2018, 2020) collected energy use data from 80 university buildings in subtropical Australia in order to establish an energy benchmark system. They analysed energy consumption, energy use intensity and related space types and occupancy conditions. The energy use of artificial lighting related to disciplines, activities, climates and the building size. Libraries and research buildings on average consumed more energy than other types of buildings. A considerable difference was found in energy use intensity in research buildings compared with other building types such as those for teaching, academic offices, administration offices and libraries. However, it is shown that increasing the research space alone does not lead to a significant increase of building energy consumption, while increasing the teaching space has a greater energy impact. For lighting, it was found that zoning is necessary to suit personal needs and uses in open plan offices.

Laboratories are supplied with intensive HVAC and lighting systems, and wet laboratories especially consume more energy than normal academic offices. Besides, laboratories have diverse end-use energy and occupancy patterns. Some laboratories are used for a few hours, whereas other laboratories are used all day long and even for some days continuously.

Gou et al. (2018) also conducted a questionnaire survey on occupant satisfaction with indoor environmental quality (temperature in summer and winter, air quality, lighting and acoustics) for selected university buildings (5 Green Star certified and 9 non-green buildings) accommodating office spaces for academic and administrative staff in subtropical Australia. Green buildings gave occupants satisfaction in non-environmental factors such as building design and image, needs for facilities, cleaning, availability of meeting rooms and storage.

Green buildings do not always give higher satisfaction in indoor environmental factors. The study revealed weakness of green buildings in the indoor environmental quality such as noise, ventilation and artificial lighting. The green buildings studied have common design elements such as a central atrium, open-plan offices and use of plants and vegetation in interiors, and design strategies of natural ventilation and daylighting. However, such a design approach resulted in performance weakness in noise, air quality and artificial lighting.

In comparison between green and non-green building groups, the satisfaction with overall lighting showed no significant difference, but slightly higher scores on daylighting were reported in green buildings. It is considered that, in green buildings, more attention is paid to daylighting design, while artificial lighting design is likely to receive less attention. This would lead to lower satisfaction scores on artificial lighting, for example, too little artificial lighting and glare from artificial lighting. Individual controls of heating, cooling, ventilation, lighting and noise were only significantly correlated with satisfaction scores in non-green buildings, but did not significantly affect the occupant satisfaction in green buildings.

A study on the energy performance of school buildings in Taiwan (2016) shows that air conditioning and lighting were key factors in the energy consumption of school buildings. In the study, 74 schools distributed throughout Taiwan were sampled, including 51 universities, 7 high schools, 11 middle schools and 5 elementary schools. Average energy use per person of the universities was 1855 kWh/person/year and considerably larger than 734 kWh/person/year for the high schools, 310 kWh/person/year for the middle schools and 289 kWh/person/year for the elementary schools. It is not surprising because of complex functions of the university. Characteristics of space use are complex and school hours are difficult to calculate in comparison to high, middle and elementary schools. Universities tend to rely on air conditioning to make indoor spaces comfortable. By contrast, in middle and elementary schools, windows are opened and electric fans are operated as an alternative to air conditioning. This is the case with other countries like Japan, but air conditioning is becoming gradually common in middle and elementary schools due to scorching heat in summer months. It is mentioned for lighting that adopting LED lights is an alternative way to substantially reduce the energy use.

Pisello et al. (2016) studied how occupants' personal attitudes and habits affect indoor environmental behaviours in a university research building in central Italy. Researchers' office rooms were continuously monitored concerning indoor visual-thermal comfort parameters, electricity consumption and door/window opening rate in spring, summer and winter conditions. Outdoor weather data were collected on the roof of the building. Occupants surveyed were considered as peers having the same job, similar age (25 to 30 years old) and similar educational level. Their working schedule was also considered as theoretically the same.

Data analyses indicated that personal preference and perception affect indoor thermal controls. Personal habits and perception also influenced illuminance over the work plane, even though occupants do the same job with very similar working schedules. The study found the necessity to consider detailed occupancy models for predicting thermal-energy and lighting behaviour.

Wang and Shao (2017) conducted an experimental study to monitor occupancy patterns for 24 hours in a university library building in the UK over 30 days (15 days in the summer term and 15 days in the summer vacation). A Wi-Fi based indoor positioning system was used in the study. It was found that users were concentrated in the seated area during the term time, while they were more in the circulation areas during the vacation. Although the library operates a 24-h opening policy during the term time, the most popular period was found to be 3 p.m. to 10 p.m. Users were a few between 1 a.m. and 9 a.m. This implied that optimizing space use and opening hours could reduce wasteful energy use for lighting and other building services.

Gou et al. (2018) studied impacts of outdoor views on students' seat selection and seating behaviours at workstations of a university library building in Australia. Workstations selected for the study are located in the periphery of the library space at level 3. A questionnaire survey showed that quiet was most frequently mentioned and views came in second for the seat selection. Sky views and shading views were found positively related to the occupancy rate.

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3.5 Hospitals

The literature review shows that boundary conditions of hospital/ health care buildings use are associated with energy, space use, light, sound and thermal. These factors determine the conditions of comfort and are important issues to be considered when developing the architectural design of healthcare service environments. Instead of typologies such as offices, schools, commercial and industrial buildings, in the typology of hospitals there is a constant occurrence of critical and stressful situations involving interpersonal relationships and individuals with some degree of physical and / or psychological suffering. They can, therefore, serve both for the well-being of users as employees, patients and family members who are weakened by the situation in which they find themselves, as well as for the recovery and treatment of the sick.

Firstly, the occupancy behaviour in hospital/ healthcare units are influenced by the space use (Figure 15). The space use can be related with design strategies, evidence-based design strategies or positive distractions. The evidence-based design strategies can bring special comfort, safety and security, autonomy, sensory comfort or sense of privacy. And the positive distractions can bring through exterior views, art works and access to nature.

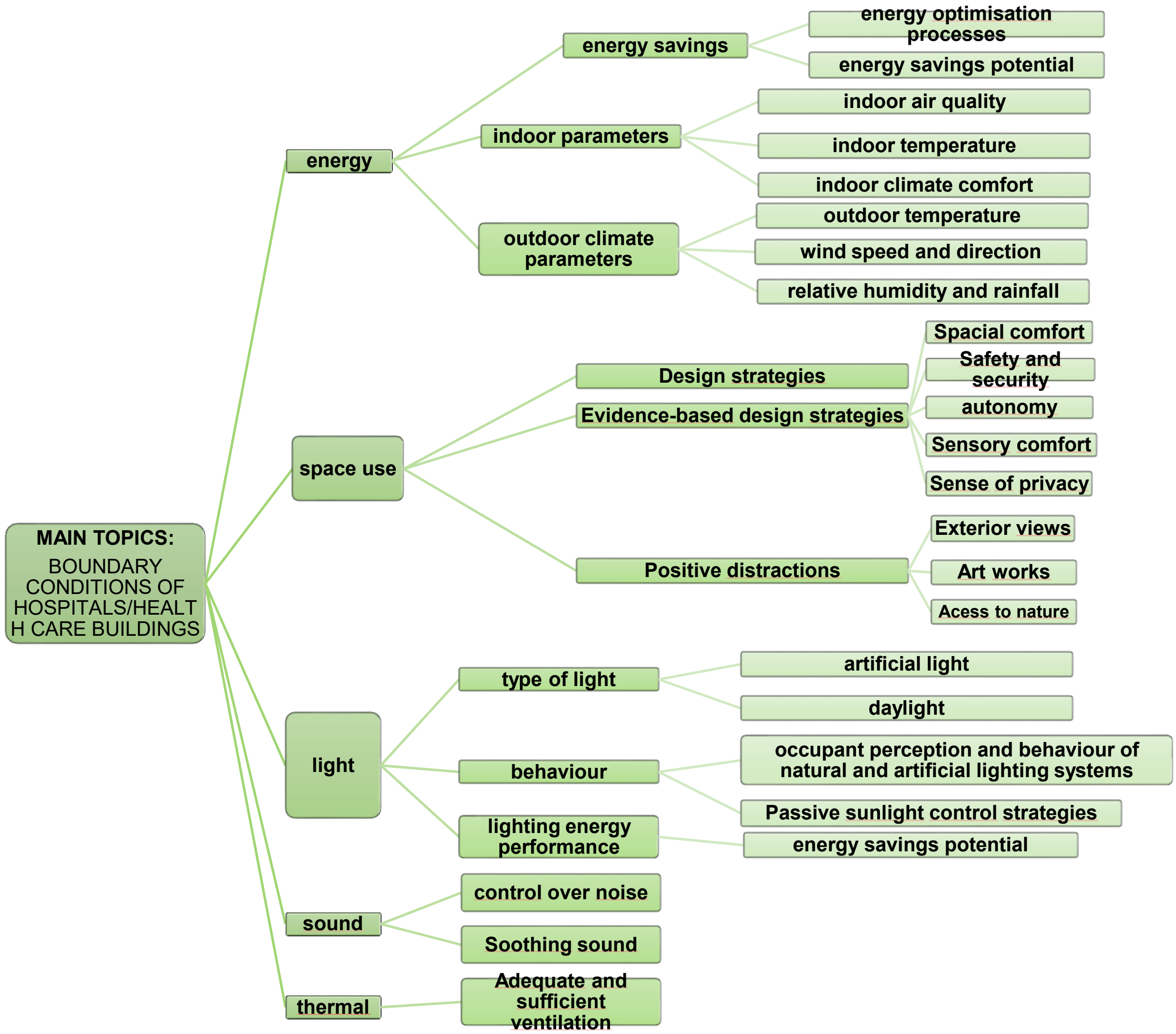

Fig. 15. detailed information of qualitative literature review of hospital

Second, the occupancy behaviour in hospital/ healthcare units are influenced by energy, which is influenced by indoor parameters, outdoor climate parameters and is related with energy savings (Figure 15). The indoor parameters can evaluate the indoor air quality, indoor temperature and indoor climate comfort. The outdoor parameters are the outdoor temperature, wind speed and direction, relative humidity and rainfall. The parameter of energy saving can be associated an energy optimisation process and energy savings potential.

Third, the occupancy behaviour in hospital/ healthcare units is influenced by light, which is influenced by the type of light, behaviour and affects the lighting energy performance (Figure 15).

Sound can influence the occupancy behaviour in hospital too (Figure 15). The sound can be related with control over noise and soothing sound.

Thermal conditions also can influence the occupancy behaviour in hospital/healthcare unit and is related with the ventilation (Figure 15).

3.5.1 Evidence-based design

Several studies have found an association between the physical environment and human health and wellbeing that resulted in the postulation of the idea of evidence-based and patient-centred design of healthcare facilities. The literature about health care environments and patient outcomes considers three research themes: patient involvement with healthcare (e.g., the role of patient control), the impact of the ambient environment (e.g., sound, light, art), and the emergence of specialized building types for defined populations (e.g., Alzheimer's patients). The research describes the challenges presented in doing high-quality research focused on health care environments and contrasts the contributions made by two different traditions: architecture and behavioural science (DEVLIN, ARNEILL, 2003). For example, to investigate the physiological and psychological effects of windows and daylight on registered nurses. To date, evidence has indicated that appropriate environmental lighting with characteristics similar to natural light can improve mood, alertness, and performance. The restorative effects of windows also have been documented. Hospital workspaces generally lack windows and daylight, and the impact of the lack of windows and daylight on healthcare employees' well-being has not been thoroughly investigated. The findings support evidence from laboratory and field settings of the benefits of windows and daylight. A possible micro-restorative effect of windows and daylight may result in lowered blood pressure and increased oxygen saturation and a positive effect on circadian rhythms (as suggested by body temperature) and morning sleepiness (ZADEH et al., 2014).

Understanding the physical characteristics of the indoor environment that affect human health and wellbeing is the key requirement underpinning the beneficial design of a healthcare facility (HCF). It was reviewed and summarized physical factors of the indoor environment reported to affect human health and wellbeing in HCFs. According to the literature, there is strong scientific evidence to show that following indoor environmental factors have beneficial effects for all user groups when appropriately designed or implemented: the acoustic environment, ventilation and air conditioning systems, the thermal environment, the visual environment (e.g. lighting, and views of nature), ergonomic conditions and furniture. In contrast, the effect of special layouts and room type and floor coverings may be beneficial for one group and detrimental for another. Some of the physical factors may, in themselves, directly promote or hinder health and wellbeing, but the factors can also have numerous indirect impacts by influencing the behaviour, actions and interactions of patients, their families and the staff members. The findings of this research enable a good understanding of the different physical factors of the indoor environment on health and wellbeing and provide a practical resource for those responsible for the design and operation of the facilities as well as researchers investigating these factors. However, more studies are needed in order to inform the design of optimally beneficial indoor environments in HCFs for all user groups (SALONEN et al., 2013).

According to the literature, the most beneficial design elements were single-bed patient rooms, safe and easily cleaned surface materials, sound-absorbing ceiling tiles, adequate and sufficient ventilation, thermal comfort, natural daylight, control over temperature and lighting, views, exposure and access to nature, and appropriate equipment, tools and furniture. The effects of some design elements, such as lighting (e.g., artificial lighting levels) and layout (e.g. decentralized versus centralized nurses' stations), on staff and patients vary, and the best design practice for each HCF should always be formulated in co-operation with different user groups and a multi-professional design team. The relevant guidelines and standards should also be considered in future design, construction and renovations, in order to produce more favourable physical indoor environments in HCFs (SALONEN et al., 2013).

Incorporating physical environmental factors into hospital design can facilitate better user satisfaction, efficiency and organisational outcomes. Many of the design interventions convey positive distractions for patients and staff, in terms of views of pleasant outside vistas, soothing sound, artwork and music. Well-designed physical settings play an important role in the healing process of patients in health care facilities. The challenge then is to fully understand that role in the ecological context of health care (IYENDO et al., 2016).

In recent years, the effects of the physical environment on the healing process and well-being have proved to be increasingly relevant for patients and their families (PF) as well as for healthcare staff. The discussions focus on traditional and institutionally designed healthcare facilities (HCF) relative to the actual well-being of patients as an indicator of their health and recovery. Evidence-based design has become the theoretical concept for what are called healing environments (HUISMAN et al., 2012).

3.5.2 End-user perceptions

There is an association between the physical environment and human health and wellbeing that brings idea of evidence-based and patient-centred design of healthcare facilities. The key challenge is that most of the underpinning research for the evidence base is context specific, the use of which in building design is complex, mainly because of the difficulties associated with the disaggregation of findings from the context. On the contrary, integrating patients' perspectives requires an understanding of the relative importance of design indicators, which the existing evidence base lacks to a large extent (ZHAO et al., 2012).

Researches are important to investigate users' perception like a key design indicator in enhancing their accommodation environments in hospitals. The patients decide that the item, design for cleanliness, was ranked as most important, closely followed by environmental and safety design indicators. The item, entertainment facilities, was ranked lowest. The item, pleasant exterior view had the second-lowest mean score, followed by the item, ability to customise the space. Age, accommodation type and previous experience of hospitalization accounted for statistically significant differences in perceptions of importance of various constructed design dimensions (ZHAO et al., 2012).

There is a growing interest among healthcare managers and designers in moving towards a 'patient-centred' design of health and care facilities by integrating patient perceptions and expectations of the physical environment where care takes place. Increased interests in physical environments can mostly be attributed to our improved understanding of their role in patients' health outcomes and staff productivity. There is a gap in the literature on users' perspectives on physical settings in the context of healthcare. Moreover, the connection of care services with the design of the facility is often overlooked partly due to the lack of evidence. Research aimed at filling this gap by exploring outpatients' perspectives on design factors. Female outpatients were found to be more perceptive of the 'sensory design' factors than males. The number of previous visits to the hospital was found to be associated with 'spatial' and 'seating design' factors, while respondents' age had an association with 'sensory' and 'seating design' factors. Respondents ranked 'noise' and 'air freshness' and 'cleanliness' as highly important (ZHAO et al., 2017).

There are end-user impressions and experiences that can be identified for improve a spatial hospital like atmosphere (abundant natural light and low noise levels), physical spaces (single occupancy rooms, rooms clustered into clinical pods, medication rooms, and trade-offs of larger spaces), family participation in care (family support areas and social networks), and equipment (usability, storage, and providers connectivity). Abundant natural light is the design feature most frequently associated with a pleasant atmosphere. End-users can be identify design elements for creating a pleasant atmosphere, attention to the trade-offs of space and size, designing family support areas to encourage family participation in care, and updating patient care policies and staffing to reflect the new physical space as important aspects to consider when building intensive care units (FERRI et al., 2015). Evidence-based design may optimize structure for patients, patient families and providers.

3.5.3 Neonatal intensive care unit lighting

Neonatal intensive care units are a special lighting design challenge. Although natural light is highly desirable, it should be carefully planned to maximise benefits and minimise the problems associated with uncontrolled sunlight. Research should discuss the performance of different passive sunlight control strategies in a neonatal intensive care unit, because it is necessary optimise the use of daylight in neonatal intensive care units, considering the special lighting conditions required. The adequate implementation of solar control systems and the appropriate layout of the space for different uses according to surrounding building design and the characteristics of the local luminous climate can increase the useful daylight illuminance by up to 13%, while avoiding the incidence of direct sunlight at all times (VILLALBA et al., 2016).

Achieving adequate lighting in neonatal intensive care units is a major challenge: in addition to the usual considerations of visual performance, cost, energy and aesthetics, there appear different biological needs of patients, health care providers and family members. Communicational aspects of light, its role as a facilitator of the visual function of doctors and nurses, and its effects on the new-born infant physiology and development is necessary address in order to review the effects of light (natural and artificial) within neonatal care with a focus on development. The role of light in regulating the new-born infant circadian cycle in particular and the therapeutic use of light in general is very important (RODRÍGUEZ, PATTINI, 2016)

The interactive development theory indicates that the new-born baby actively responds to the environment looking for balance. These dynamics offer beneficial opportunities for preventive and therapeutic interventions.

A lot of recommendations are done about light in these spaces. It is necessary to generate points of interest, either by contrast or by colour, emphasizing, through lighting, desirable stimuli such as photographs or artistic images, flexible lighting system, incorporate natural light in the hospitalization area and locate cribs more than 60cm away from windows. Sealed double glazed is preferable so as to minimize heat loss and include external elements of solar control in windows, which are easy to maintain and clean, and which allow flexible use as needed. Use neutral colours to minimize colour distortion. Avoid direct sunlight radiation both on patients and on IV fluids and data display screens. Examine the infant, the colour of their skin and mucous membranes, and their perfusion anywhere in the room, with a range of general illumination of 10-600 lux. Use individualized light sources of, at least, 2000 lux to examine the new-born infant or to perform specific procedures in short periods avoiding the exposure of nearby patients. Interior surfaces (walls, floor, ceiling) should be clear with a matt finish so that the interior light is distributed diffusely to avoid glare. Sources of artificial lighting must have a CRI greater than 80. Their optical reflectors must have a natural finish to maintain the properties of colour rendering. Limit visual stimulation that competes with auditory and tactile information prevailing in a NICU to avoid sensory interference during this stage of development. Always avoid direct light to the new-born infant's eyes. Use progressive lighting to enable a gradual dark-light shift to reduce the stress produced in the new-born infant by a sudden change in ambient lighting. Implement a cyclic lighting schedule. During the day, between 100 and 200 lux, with some natural light. At night, artificial light lower than 50 lux, with a natural light like spectral distribution. Day/night lighting should be capable of increases up to 600 lux with independent control for separate lights. The use of individual blankets is an alternative, and a higher mean duration of non-REM (rapid eye movement) periods has been reported in stable preterm infants protected by blankets. Lamps in the blue region of the spectrum (460- 490 nm) are the most effective ones in treating hyperbilirubinemia. When using lamps for therapeutic purposes, limit the intensity of light source to the minimum required by the task and minimize exposure time. Avoid exposing the new-born infant's eyes to ultraviolet and infrared radiation using appropriate lamps, lenses or filters (RODRÍGUEZ, PATTINI, 2016).

3.5.4 The influence of the workplace indoor environmental quality on the incidence of psychological and physical symptoms in intensive care units

The literature about the influence of the workplace indoor environmental quality on the incidence of psychological and physical symptoms in intensive care units aimed to investigate the risk of symptomatologic complaints resulting from exposure to indoor environmental quality variables in intensive care units (ICUs) and to determine the exposure risk caused by the interaction of these variables. The results indicated that the ICUs were at the limits of the hygienic standards stipulated for the sector; employees working had a 42.2% probability of experiencing physical symptoms associated with environmental discomfort and a 45.3% probability of experiencing psychological symptoms associated with environmental discomfort, representing increases of 24.5% and 6.9%, respectively, above the basal probability. The variables with the highest impact on the health of professionals were temperature variables, which were estimated using the average rating predicted by ISO 7730/2005 and self-reported perceptual variables (VIEIRA et al., 2016). The interaction between environmental attributes in a risk scenario indicated that the environmental temperature could affect other environmental variables that impact the health of professionals.

Hence, the risk arising from an uncomfortable environment is not simply the sum of the individual risks for each attribute; rather, it is the result of synergy between the measurable and perceived variables.

In this study were found important things. The change from a comfort state could generate an 11.4% increase in the probability of having an increased number of physical symptoms and a 9.6% increase in the probability of having an increased number of psychological symptoms (VIEIRA et al., 2016). About light, on a perceptual level, the change from a state of satisfaction with the lighting to dissatisfaction increased the risk of physical symptoms from 37.5% to 49.3% (an increase of 11.8%) and the risk of psychological symptoms from 40.2% to 49.2% - an increase of 9% (VIEIRA et al., 2016). The sensitivity analysis of the "noise perception" node showed a peculiar result. In this case, the state of discomfort reduced the risk of developing symptomatologic complaints by 1.7% compared with the "not uncomfortable" node, which increased the risk by 4.9% (VIEIRA et al., 2016).

3.5.5 Energy saving in hospital patient rooms: the role of windows size and glazing properties

Large windows with increased exposure to daylight have strong positive effects on the well-being of building occupants and can provide energy savings when appropriate glazing specifications are employed. It is necessary evaluates the impact of different window sizes and glazing on heating and cooling energy needs in a hospital patient room, in order to investigate the energy savings achievable by adopting wider openings and to identify the most effective glazing types. Simulations with different commercially available glazing systems show that the adoption of wider windows with appropriate glazing can lower the heating and cooling energy demand (CESARI et al., 2018).

A significant discrepancy was founded between the values of the heating energy and the cooling needs, a difference between the achievable percentage savings, as well as an opposite trend between the glazing specifications allowing to reach the maximum heating energy savings and those appropriate for the cooling ones. These observations highlight the need to consider the two types of energy demand separately and the city. With appropriate glazing specifications, the adoption of wider windows enables to reduce the patient room heating energy requirements by increasing the amount of solar heat gains and minimizing the thermal transmission losses. However, windows with higher WWR increase the cooling energy needs, which can be significantly reduced using appropriate glazing types and shading systems (CESARI et al., 2018).

3.5.6 Study of indoor environmental quality and occupant overall comfort and productivity in certified healthcare settings

The study combined quantitative and qualitative approaches, in terms of both staff perception and facility manager perspective, to evaluate the effectiveness of indoor environmental quality (IEQ) of LEED–certified facilities and relationship between IEQ and occupant comfort and productivity in healthcare settings in the USA climate zones 2 and 3. A multiple-methods approach combining a questionnaire survey and semi-structured interview was tested for effective post-occupancy evaluation. The study compared one non-LEED healthcare facility with five LEED certified healthcare buildings and examined which variable(s) had significant relationship with comfort and productivity by surveying 249 occupants and interviewing six facility managers in six healthcare settings. The results showed that five LEED – certified healthcare settings were superior to one non-LEED facility in most of building performance factors. Building design, temperature comfort, image presented to visitors, use of space, control over noise and ability to meet occupants' needs were significant predictors for overall comfort. Lighting overall, temperature comfort and image presented to visitors had a significant positive relationship with perceived productivity. Only one non-LEED hospital was selected, and some buildings had small response rate, the results should be interpreted with caution (XUAN, 2018).

Staff in healthcare facilities that incorporated LEED IEQ credits had a higher satisfaction level regarding building performance variables, overall comfort and perceived productivity than one non- LEED healthcare facility. Carefully should be select an energy-efficient lighting system, such as LEDs. And It is necessary improve personal control of building systems in healthcare settings. According to the statistical findings and facility manager interviews, controllability of building system are very important; however, based on the staff-reported low scores of controllability in both LEED and non-LEED facilities, it does not get much attention from designers and managers (XUAN, 2018).

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3.6 Commercial buildings

The buildings that are associated in the literature with the title of “commercial buildings” have a huge variety of functions. They vary from small retail stores to complex shopping malls. The most challenging part of this literature review was filtering the commercial office building which is described in section (REF) in this report. In this part, the aim was to review the main topics related to lighting, both daylight and electric, in commercial buildings.

It seems that the competitive nature of commercial spaces and easy access to the financial sources usually put the owners of commercial buildings among the first group who try new technologies in their buildings, especially in lighting, to attract the attention of the potential costumers to their products as a marketing tool. The literature review shows that the boundary conditions of use in this category is associated with i) the occupancy behavior influenced by atmospheric elements as a marketing tool, ii) lighting technology (luminaries and lamps), iii) energy consumption, iv) lighting control strategies, and v) integration of daylight and electric light.

Despite variations in the function and the products in a commercial building, shopping behavior looks similar. C. W. Park, Iyer, and Smith looked at grocery shopping experience which constitutes an essential and routine type of consumer behavior (C. W. Park, Iyer, & Smith ,1989). They characterized the shopping experience in two categories: the multiple buying goals that must be achieved through the processing of a complex array of in-store stimuli such as products, brands, and point-of-purchase information, and the repetition at regular time intervals. In this review, we approach the topic in the similar way, i.e. by considering the effect of lighting on the environment where these services are provided.

The priorities of lighting in commercial buildings have changed and developed over the years. Stickney wrote that the inadequate wire capacity was the major problem with providing sufficient illumination to meet the requirements of the light users in the commercial environment during the 1920s (Stickney, 1929). After rapid advancement in the efficiency of tungsten filament lamps, the demands for better lighting increased and competitive situation between designers of lighting installation to find more potential clients has led them to use inadequate lighting to secure savings in initial costs and resulted often with occupants who were not satisfied with the lighting output. Stickey is among the pioneers who emphasized the priority of providing user comfort in lighting design and advised that “the amount of wiring or lighting installation should not follow by the cost or any other issue other than user satisfaction”.

After World War II, the owners of commercial buildings had the chance to invest money in lighting as a tool to attract customers. In 1966, Roper wrote: "15 years ago shop lighting was still recovering from wartime restrictions and the need to economize in fuel, but shopkeepers quickly, and vary widely, opted for the new medium, fluorescent lighting, which appeared to them to have every advantage.” In this time while the general lighting of commercial spaces was fluorescent, the use of filament lamps had increased for displays by offering a greater light concentration by spotlighting or accent lighting and “dramatic” effects. It is important to have in mind that in 1961 the standard for light on work surfaces was 15 lm/ft2 (about 160 lx) (Roper, 1966).

Increase use of light for safety and atmosphere arise concerns about energy consumption and energy efficiency in the 1960s. The main energy concern in this time in Roper’s opinion was the heat produced by the lighting even by modern high-efficiency light sources. He suggested that in the total loading of the building installation, considering the heat load of the lighting system is necessary (Roper, 1966).

3.6.1 Atmospheric elements as a marketing tool

In 1973 Kotler claimed that atmospheric elements can be used as a marketing tool. Although he was not the first person who discussed the topic, his research received a lot of attention and different groups of researchers did grand experiments to test his idea in real commercial buildings with a verity of functions.

Kotler aimed to understand the people’s purchase decision-making and response by developing a systematic exposition of the atmosphere as a buying influence. He defined the atmosphere as “the effort to design buying environments to produce emotional effects in the buyers that enhance his purchase probability.” Kotler identified that atmospheric factors including visual (color, brightness, size, shape), aural (volume, pitch), olfactory (scent, freshness), and tactile (softness, smoothness, temperature), and the dimension of the store, affect consumers purchase behavior (Kotler, 1973).

One year later, Mehrabian and Russell also pointed out that the combined effects of pleasure, arousal, and dominance influenced people's behavior in particular environments (Mehrabian & Russell, 1974). The paradigm of the stimulus-organism-response (S-0-R) in the M-R model explained that an individual's emotional states (0) aroused by the environment mediate between the physical environment (S) and human behavior (R) interaction. (N. K. Park & Farr, 2007) "Mehrabian and Russell posited that three emotional states mediated approach-avoidance responses to an environment. These were pleasure (the degree to which a person felt happy or satisfied in a place), arousal (the degree of stimulation caused by an atmosphere), and dominance (the degree to which a person feels in control in a situation)" (Turley & Milliman, 2000). Mehrabian believed that lighting as a chief factor in the environment's impacts on individuals' arousal. In another way, people shop to increase their arousal and pleasure levels. Mehrabian theorized that brighter light increases arousal and a combination of arousal with pleasantness make individuals more susceptible to influence (Summers & Hebert, 2001).

3.6.2 The influence of lighting on user behavior

(Wardono, Hibino, & Koyama, 2012) also introduced light as one of the facility aesthetics that can act as visual cues of the key experience for designing a memorable experience. Some sources like Mehrabian's theory consider the brighter environment as a stimulus, especially in the marketing approach, and they claim that the brightly lit environments are more arousing than dimly lit ones. At the same time, some suggest that retailers who wish to slow the shopping pace should dim down the light in their store (Areni & Kim, 1994). This implies that the selection of in-store lighting levels can influence the amount of time that customers spend shopping.

In the study conducted by Areni and Kim, a wine cellar of a restaurant was observed over 2 months (Areni & Kim, 1994). They applied the M-R model by lighting manipulation "soft" versus "bright". Areni and Kim found that brighter in-store lighting influenced shoppers to examine and handle more of the merchandise, especially at eye level. In a similar approach by (Summers & Hebert, 2001) consumers touched and picked up more items with the addition of display lighting in a brighter situation. However, in Areni and Kim's research, the effect of lighting on the amount of time spent in the store, and total purchases were not significant.

In terms of time spent in a store, other associated variables are music, color and pleasure (Turley & Milliman, 2000). Another key point, the findings suggest that when in-store lighting levels are lower the shoppers will be less likely to engage in visually oriented activities like checking prices or reading labels (Areni & Kim, 1994).

Summers and Hebert believe that not only brightness but also the contrast may have influenced the consumers' behaviour (Summers & Hebert, 2001). Human visual system reacts better to changes and spatial variation within the visual field, one of them is contrasts. In their study, they found that age also is an important factor in user behaviour related to the light level and contrast, e.g. children spent relatively more time at the test displays than older costumers did.

Approximately one-half of all grocery purchases are unplanned and the study by Park, Iyer, and Smith shows that one-third of the unplanned buying decisions occur due to the triggering of new needs via the active processing of in-store information (C. W. Park, Iyer, & Smith, 1989). This shopping decision is related to the environment of the store which affects the respondents' knowledge of the arrangement and their available time for shopping and can influence the function of rehearsed memory to buy the items, brand switching, and the level of purchase volume deliberation.

Interesting research, (Horská & Berčík, 2014) measured the effect of lighting on an individual's perception in the fresh food market, by using a questionnaire survey and also conducting a neuro-marketing pre-test. They compared five different types and alternative forms of lighting and monitored the brain reaction of costumers. The different types of accent lighting stimulate different parts of brain reactions, which shows that light actually affects consumer reactions consciously and subconsciously. The results of brain monitoring showed that the most subconscious reactions were triggered by fluorescent lighting, which is commonly used in commercial buildings, and the most emotional aspects by metal halide lighting. On the other hand, on the basis of visual evaluation, the respondents rated halogen lighting as the most attractive and metal halide and LED lighting were rated as creating the least attractive lighting effect. In another part of their research (Horská & Berčík, 2014) found that various types of lighting change the rhythms of brain activity and that the right hemisphere of the human brain is more involved. The intensity of this reaction varies with the type and color of lighting. The yellow light was rated highest for the positive effect at the fresh food section, both in the survey and responses from the subconscious of the respondents, while the green color of light had the most emotional effects.

3.6.3 User cultural context (Perception of brightness, CCT and CRI)

After almost three decades from Kotler's idea, Turley and Milliam wrote a review on the experimental researches that have manipulated a large number of atmospheric elements, such as light, color, and other factors, and registered their influence on behavioral responses. They found that in all the researches during those years, the atmospheric effects for certain responses may produce an entirely different response in another time or different individuals or groups and commercial building designers should have a particular user in mind and narrow they target markets or consider human factors associated to the backgrounds, and preferences to be able to induce more consistent behavior from more than one culture (Turley & Milliman, 2000).

The color render and color appearance of light are important factors, especially when considering lighting design in a retail store environment. (Park & Farr, 2007) suggest that using cool color lighting could be beneficial when the emotional state of arousal, visual clarity, and approach intention is required in retail locations such as electronic stores, book stores, sporting goods stores, and so on. However, using warm color lighting in a store as a gift boutique or a high-end clothing store would be helpful if the emotional state of pleasure and store attractiveness were desired.

With the intention of observing the cultural differences in perception of light, Park and Farr conducted a cross-cultural comparison of the quality of light including brightness, Correlated Color Temperature, and Color Rendering Index. They studied differences in emotional states, perception, and behavioral intentions between American and Korean consumers in a retail environment. “It has been determined that perceptual patterns are learned and culturally determined and the color quality of light in an environment may contain meaning, produce emotional states, and reveal different behavioral intentions depending on the cultural context” (Park & Farr, 2007).

3.6.4 Development of lighting technology and energy concerns

Commercial buildings account for 19% of energy consumption (Song & Ji, 2014), and lighting accounts for about 20% of all commercial building energy consumption (Lawrence & Crawley, 2008).

Lighting measures have been identified as one of the most effective strategies for reduction energy use in commercial buildings and there is a belief that reductions in lighting energy, by its secondary effects, will reduce the cooling and heating energy consumption and peak HVAC requirements of a building. In a study (A. O. Sezgen, Huang, Atkinson, Eto, & Koomey, 1994) believe that it is safe to assume that generally the heating/cooling demands and the annual heating load will not be affected seriously by lighting energy. On the other hand, they noticed a considerable change in the annual cooling load. In another research by the same group (2000), they found that the reduction in well-distributed geographically lighting energy will induce neither significant savings nor significant penalties in HVAC primary energy use or energy expenditures. Whereas, lighting/HVAC interactions in different climatic regions are substantially different than the averages. "Generally, in warm climates, the interactions will induce monetary savings and in cold climates, the interactions will induce monetary penalties.” (O. Sezgen & Koomey, 2000). It is important to consider that these studies are from the time before LEDs and more efficient lamps were introduced.

There are several different types of luminaires and lamps in the market, tungsten halogen lamps, compact fluorescent lamps, fluorescent lamps, low-pressure and high-pressure sodium lamps, metal-halide lamps, sodium-xenon lamps, electrodeless induction lamps, and the most recent one LED (Light Emitting Diode) lamps.

In commercial buildings, the concept of lighting is composed of multiple systems. Most often the basic lightings are fluorescent lamps and LEDs distributed at the selling area. Also, lamps with different color filters or color temperature are used for accent lighting. For some stores, the lighting is not just a functional need but also the only marketing tool (Horská & Berčík, 2014).

In a study by (Ahn, Jang, Leigh, & Jeong, 2014) the efficiency of linear fluorescent lamps is reported to be 5 times greater than traditional lamps. In their research, the replacement of incandescent and halogen lamps with fluorescent ones reduced the total energy requirements for lighting by up to 35%. Correspondingly, by replacing fluorescent lamps with LEDs, the total energy was reduced by 20.9% with an additional saving of 19.9% in cooling energy by using heat and dimming control method from the reference commercial buildings.

The fluorescent lighting is less easy to control and dim than LED lighting. The effective dimming ballasts that have the ability to reduce energy are not the optimal choice economically it is also difficult to apply dimming controls (Bannamas & Jirapong, 2015). Moreover, fluorescent lamps need at least 50% of the input power constantly for dimming (Ahn et al., 2014). Instead, LEDs are an inherently low-voltage source that can be more cost-effectively dimmed over a wider range. In addition, their life expectancy is not affected by frequently turning them on/off. Their frequency response relies on loads that can be switched on-off within a short period of time. Due to the low cost and rapid response, LED lighting loads in commercial buildings offer a wide margin for use as a frequency regulation source in response to frequency deviations (Liu, Zhang, & Liu, 2016). The LED dimming control case shows a higher saving effect than that of the linear fluorescent lamps case, in spite of the similar efficiency of both lamps (Ahn et al., 2014). Therefore, more amenable control strategies allow practitioners to capture additional energy savings (Williams, Atkinson, Garbesi, Page, & Rubinstein, 2012) specially to let taking daylight contributions into the account.

3.6.5 Difficulty of tracking the long-term and short-term occupants

If occupants can adjust their behaviors, 20% of energy can be saved without retrofitting (Song & Ji, 2014). The process of modifying the behavior of the occupants of commercial buildings is challenging. The difficulties are related to major issues like; number of occupants (it is extremely difficult to estimate the energy load of a single occupant from a large group of people), term of stay (a great portion of occupants in commercial buildings are temporary and the data collection time is becoming a crucial factor), feedback (occupants in commercial buildings are not responsible for the payment of energy bills therefore they don’t receive consistent feedback to modify their behavior) (Chen & Ahn, 2014).

The concept of short-term and long-term residence in a commercial building was deliberated in 2014 by Chen and Ahn. They believe that to identify personal energy consumption in buildings, the differentiation of long-term residents from short-term residents is very important. In commercial buildings, short-term residents do not have direct control over energy-consuming facilities. Estimating the energy load of long-term occupants and temporary occupants is essential to improving energy consumption predictions and to supporting the development of feedback systems. Occupants in commercial buildings are individual stakeholders, who need to know their personal energy consumption to be motivated in taking actions toward energy efficiency in buildings. Accordingly, for load monitoring approaches in commercial buildings, the location of the consumption is also important in addition to time and level of consumption (Jazizadeh & Becerik-Gerber, 2012).

The complications in tracking the energy consumptions of various residents and tracking occupants' behavior, as well as the difficulty of providing feedback, contribute to the research gap in tracking energy load for occupants in commercial buildings. It is proven that providing energy-consumption feedback is an effective approach for changing residents’ energy consumption behavior to save energy since the most successful intervention techniques applied to residential energy-consumption with billing feedback (Chen & Ahn, 2014). In commercial buildings, occupants are not directly in charge of electricity consumption costs, and therefore, they are not aware and motivated to improve energy-related behavior to increase energy efficiency (Jazizadeh & Becerik-Gerber, 2012).

With this in mind, (Azar & Menassa, 2012) proposed using Wi-Fi systems as a tool that uses residents’ wireless devices’ Wi-Fi connection and disconnection to detect occupancy and then benchmarks energy loads for individual consumption monitoring. Also, in another approach, to invite occupants into the control loop (Song & Ji, 2014) suggested an energy management dashboard and a control system to encourage occupants to adopt energy-aware behaviors by a calculation method based on game theory which is formulated as a multi-objective optimization problem.

3.6.6 Occupant behavior agent-based modelling

The human behavior model encompasses the three processes that are essential in initiating behavior research: define behaviors, identify behavior triggers, and measure/quantify behaviors. Depending on the level of comfort dissatisfaction, the number of behaviors to be considered may vary reasonably and often spontaneously from the information or beliefs people possess about the behavior under consideration. These are "Behavioral beliefs" (beliefs about the positive or negative consequences); "Control beliefs" (Beliefs about personal and environmental factors that can help or impede occupants' attempts to carry out the behavior); "Normative beliefs" (beliefs that important individuals or groups in their occupants' lives would approve or disapprove) (Lee & Malkawi, 2014).

The influence of other shoppers and the influence of retail employees on user behavior are the general human interaction in commercial buildings. The influence of other consumers is considered as an environmental variable by a focus on the crowding issue which in a retail store involves two components, actual shopper density and perceived crowding (Turley & Milliman, 2000).

In the general occupant modelling, it is assumed that all occupants have similar schedules, consume energy at the same rates, and never change their energy consumption behavior over time. This is not accurate, e.g., occupants might tend to use more electric lighting following the installation of a new set efficient lights, assuming that their actions will have less impact on the environment but in contrast as a "rebound effect" their behavior will have negative impacts on energy use which usually is not predicted in energy simulation software programs. To address this, (Azar & Menassa, 2012) considered the peer-peer influence or workshops effect on learning and changing the energy consumption behavior in occupants. They proposed new agent-based modelling by accounting for the diverse and dynamic energy consumption patterns among occupants, in addition to the potential changes in their energy use behavior attributable to their interactions with the building environment and with each other, also their change over time. In their study, the changes in energy consumption levels calculation reflects the dynamic aspect of occupancy.

(Lee & Malkawi, 2014) believe that the closeness between agents that establish social connectivity are the factors that influence the rate of agent behavior execution which, for instance, would be higher if all agents are of a parallel social status (colleagues), rather than a vertical social status (boss and worker or in commercial environments shopkeeper and costumer).

3.6.7 Daylight

Daylight was the primary source of interior lighting but the cost, convenience, and performance of electric lighting replaced it especially in commercial buildings. This approach made the lighting one of the largest consumers of electricity in commercial buildings nowadays (Muhs, 2000).

In many standards and energy codes the use of daylight is very limited due to the thermal concerns. Some building owners, researchers, and top lighting practitioners believe that daylighting may provide other benefits like increased occupant health and well-being, which could increase productivity or sales (Lawrence & Crawley, 2008).

Challenges associated with daylighting include the cost of windows/skylights and lighting control systems, added design complexity to ensure sitting and interior space facilitates; glare management (large intensity variations); and implementation of effective lighting controls (Lawrence & Crawley, 2008). The review by (Williams et al., 2012) also shows that simulations significantly overestimate (by at least 10 percent) the average savings obtainable from daylighting in actual buildings.

Additionally, (Azar & Menassa, 2012) believe that building occupants that actively seek daylighting rather than systematically relying on artificial lighting can reduce overall primary energy expenditure by more than 40% compared with occupants who constantly rely on artificial lighting.

3.6.8 Atrium and glazed spaces

In commercial buildings, highly-glazed spaces are attractive in many ways by providing daylight, solar heating, aesthetics, etc., however, their thermal behavior remains difficult to predict. Energy use and comfort issues are often either inadequately addressed or discarded, especially at the early stages of design. The governing heat transfer phenomena encountered in large highly-glazed spaces are significantly different than those encountered in conventional buildings (Voeltzel, Carrié, & Guarracino, 2001).

As the atria are glazed, the impact of the temperature of the façade on thermal stratification and comfort is important. Solar radiation is the major heat gain in an atrium and the colder surfaces warm up by radiant heat and these surfaces then become secondary convective heat sources (Lau & Niu, 2003).

The increasing popularity of double façades in these spaces and their relative complexity in physical terms—with issues such as thermal and visual comfort, cooling load during summertime, heat loss during wintertime, ventilation, acoustics, moisture and fire safety requiring consideration makes support from building physicists indispensable for designers. Especially the total solar energy transmittance to the interior is of key significance for the cooling load of the building and thermal comfort of its occupants (Manz, 2004).

In a study by (Lau & Niu, 2003) a 25m high exhibition atrium was monitored by using the measured surface temperatures as boundary conditions and simulation by taking into account the influences of occupant load, equipment load, lighting load, floor and wall surface temperatures, and supply air conditions to examine the vertical temperature distribution. They found that heat from overhead lighting contributed less to the increase in temperature than the heat from the occupants and equipment contribution due to the location of occupants and equipment's zone which is between the head and the feet as "occupied zone" for the air-conditioning system. While. For the space above 3 m, the temperature profile is dominated by the lighting load.

Measured data from the two atrium spaces investigated by (Atif & Galasiu, 2003) suggests that the general assumption that there is an abundance of daylight contribution to the atrium ground floor and into the adjacent spaces that automatically displace a large portion of the electrical lighting consumption is not always true. Data showed a high daylight contribution at the atrium perimeter on all levels of the space.

(Manz, 2004) believes that the total solar energy transmittance depends on outdoor conditions (air temperature, radiant temperatures, solar radiation, wind), indoor conditions (air and radiant temperatures, air velocity), façade geometry, optical (solar reflectances and transmittances) and thermal properties (emissivities, thermal conductivities) of all layers and fluid-dynamic properties.

(Lawrence & Crawley, 2008) suggest the use of opaque coating for the glasses of top-lighting windows or atriums increase the solar gain during the cooling season and decrease heating energy consumption during the heating season. Blinds are also effective in both comfort and energy performances in a hot climate to provide occupants with comfort. In a hot climate, controlling solar radiation was more effective than controlling air movement for both comfort and energy performances. However, these observations are exactly the opposite of a cold climate (Lee & Malkawi, 2014).

Researchers believe that daylight linked lighting control systems have the potential to reduce electrical energy consumption by dimming the electrical light and also less heat production due to the use of daylight in the cold season. Building energy consumption is affected by dimming or turning off electric lights when the daylight meets the standards. It reduces the cooling load by using less electric lighting (Ahn, Jang, Leigh, & Jeong, 2014) (Lawrence & Crawley, 2008).

Savings in electrical lighting energy from the use of daylight-linked lighting control systems in atrium spaces depend greatly on an adequate understanding of the daylight distribution throughout the space and the type of automated lighting system selected. Also, measured daylighting contribution to space indicates that significant lighting energy savings can be achieved in atrium spaces if the daylight-linked lighting control system is appropriately selected, the continuous dimming lighting control system provides 46% annual savings in electrical lighting consumption, while the automatic on/off saves between 11-17% in lighting energy (Atif & Galasiu, 2003).

3.6.9 Lighting control strategies

Lighting controls now offer a range of methods that are both cost-effective and energy-efficient. (Cook, 1998) classified the lighting control systems in five categories: Localised manual switching, Time-based systems, Daylight-linked, Occupancy-linked systems, Lighting Management Systems. While (Williams, Atkinson, Garbesi, Page, & Rubinstein, 2012) categorized these lighting strategies into daylighting strategies, occupancy strategies, personal tuning, and institutional tuning. Furthermore, (Bannamas & Jirapong, 2015) proposed a combined of six control lighting methods of lighting control occupancy control, time scheduling, daylight control, task control, personal control, and variable power shedding in a dimming control system together with the adjustment of the luminance levels to conserve more energy.

In detail, the results of (Williams et al., 2012) meta-analysis of 240 savings estimates from 88 papers and case studies provide strong evidence that currently-available lighting control strategies can and do provide significant lighting energy savings in commercial building applications. Their findings indicate that policies that increase the use of lighting system controls can provide a potent approach to reducing energy use and in the summary, they found out the best estimates of average lighting energy savings potential are 24 percent for occupancy, 28 percent for daylighting, 31 percent for personal tuning, 36 percent for institutional tuning, and 38 percent for multiple approaches. In another study by (Atif & Galasiu, 2003) the result shows that the savings account for 68% of the lighting energy consumed during the main occupancy for the continuous dimming system, and 31.5% for the automatic on/off.

In summary, occupancy controls have the greatest potential in spaces where occupancy varies throughout the day, and daylighting controls should only be applied in portions of the floor area where sufficient daylight exists. (Williams et al., 2012) meta-analysis shows that individual control strategies save on average between one-quarter and one-third of lighting energy, and multiple control strategies can capture up to nearly 40 percent savings on average.

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3.7 Other public buildings

3.7.1 Industry buildings

The literature review shows that boundary conditions of industry buildings are not extensively represented in scientific databases. Only very basic information on industrial buildings could be found based on following articles: (Sufar, Talib, & Hambali, 2012), (Tam, Almeida, & Le, 2018), (Hong, Taylor-Lange, D'Oca, Yan, & Corgnati, 2016), (Rashid, Singh, & Singh, 2019),

Industry buildings are usually mentioned in the context of energy, light and space use categories. These factors largely affect the conditions of comfortable and functional operation of industrial buildings. Of a great interest are energy aspects such as predicted and real energy use, which affect the economy and efficiency of industrial investments. Out of these reasons, emerging direction in literature are also occupant-based or occupant-influenced connotations. The comfort and practicality of using the space are of great importance to users. Therefore, even more attention is paid to the research on occupancy patterns and occupants' future presence and behavior in industrial buildings.

In the context of light, a distinction is made between daylight and electric light. In terms of industrial buildings, in the literature indicated are mostly manually and automatically controlled electric lighting and blinds assessed in the context of illuminance values and energy savings.

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3.7.2 Libraries

Libraries are cultural institutions that collect, store and make available variety of library materials. Despite the advanced digitization of many resources and their availability in electronic versions, traditional libraries where you can borrow and read the books or newspapers on the spot, are still popular, in particular among pupils, students and scientists. Hence, it is important to recognize the key boundary conditions for their use and occupancy.

Literature studies show that in addition to standard possible factors influencing the boundary conditions of use, the aspects related to the aesthetics and visual perception of space are important. In the context of libraries, energy issues are related mainly to thermal aspects, lighting is also growing in importance. Lighting is an especially interesting feature, since the perception and the degree of use depends in great extent on the needs of individual users.

In the energy context, libraries are being assessed not only in terms of energy-related occupant behaviour but also outdoor parameters such as outdoor temperature, wind speed and direction, relative humidity, and rainfall. All those factors can namely have an influence on overall library building energy performance and indirectly influence electric light use. The occupancy patterns and lifestyles (either ecological or non-ecological) that are visible in libraries along with occupants' perception of comfort are also of a great importance as indicated in the literature. All those factors influence radically the space use and occupants' presence and behaviour in buildings.

Of a great importance proved also to be interior ambiences caused by selection of lightings, furniture, materials and finishes. This proves the understanding that not only the functionality of libraries counts for modern users and has an impact on their occupancy behaviour, but aesthetics as well.

Adequate lighting is an obvious precondition for libraries. In the context of energy transition, there is a growing attention to energy savings and illuminance values assessment in libraries. In the libraries design it is aimed at the optimal use of daylight and electric light by the use of modern technologies and control systems - both manually operated and automatically controlled.

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3.8 Overall conclusions

The literature review shows a great variety of building types, that is, office buildings, educational buildings, healthcare facilities, commercial buildings, industry buildings and libraries. However, there is a common denominator found for factors relevant to the building use in different building types. Boundary conditions of many building types are associated with energy, space use and light conditions. Acoustic and thermal conditions are also influential in educational buildings and hospitals, where control over noise and ventilation are key factors for the comfortable indoor environment.

Energy aspects are relevant to energy saving, indoor environmental conditions, and outdoor climates. Although there are some differences in the proportion of energy consumption for electric lighting depending on the building type, lighting is one of the largest energy users among technical building systems and appliances. The energy consumption for electric lighting is highly influenced by occupant behaviour and occupancy patterns in the space. Utilization of occupancy information in building controls has a significant energy saving potential, and it is already implemented in many cases. For example, occupancy detection has been widely used for demand control of the building equipment. Occupancy profiles are also used in building simulations. Probabilistic models of occupancy using past monitoring data results in modest levels of prediction of daily occupancy profiles.

Space use is relevant to comfort, operating time, and positive distractions. It is directly linked to occupancy patterns in office buildings, and consequently influences the energy performance. For educational buildings, user-centred design is a consideration to enhance human well-being, health and performance. Children spend about 30% of their time at school. Space design and the indoor environmental quality are crucial for growing children. A design principle of naturalness accounts for approximately half of impacts of the physical classroom parameters on learning. For healthcare facilities, evidence-based and patient-based design is an important design concept. Incorporating physical environmental factors into hospital design can facilitate better user satisfaction, staff productivity and organizational outcomes.

Light conditions are relevant to visual comfort, lighting energy performance, occupant perception and behaviour of daylighting and electric lighting systems. The control strategy of electric lighting is a determinant of the lighting energy performance. In office buildings, the manual switch control with an absence detector accomplishes a good energy performance and has high occupant satisfaction rather than the full-automatic control. In school buildings, daylight-responsive lighting control can help saving energy. However, the energy performance depends on building and system parameters, climate conditions and occupant behaviour. Significant reduction in use of electric lighting and energy could be achieved by more sustainable design and management strategies including effective window design and an integrative approach to use of daylight and electric light. In hospitals, large windows with increased exposure to daylight have strong positive effects on well-being of occupants. Regardless of the building type, it is essential to employ appropriate glazing specifications to lower heating and cooling loads for larger windows.

Manual lighting control mainly coincides with the occupant's arrival at or departure from the workplace. The criterion for switching on electric lights may be correlated with darkness in the room or the work plane. The work plane illuminance of 250 lx – 300 lx indicates the minimum value for the action. In continuously occupied multi-person offices, occupants rarely switch lights off and during the day. The length of absence from the workplace strongly correlates with the probability of manually switching lights off. People in private offices with occupancy control are less likely to switch their lights off upon temporary departure.

Actions on windows commonly occur when occupants arrive or leave their offices. A study shows that internal and external temperatures are linked with actions on windows. The percentage of open windows and frequency of opening and closing windows show seasonal patterns. The percentage of open windows is much higher in summer than in winter and fluctuates in spring and autumn. Analysis of the user behaviour shows diurnal patterns of opening and closing windows. Windows are opened and closed more frequently in the morning, at lunchtime and in the evening. A study on use of window blinds shows a significant correlation between window blind occlusions and building orientations. Many occupants operate window blinds to avoid excessive daylight or glare, to have the view out, to increase the daylight level, to reduce heat gain, and to feel the warmth of the sun.

Commercial buildings have a huge variety of functions and vary from small retail stores to complex shopping malls. However, they have a common purpose of proving appealing spaces and promoting buying behaviour. Brightness, contrast, colour rendering and colour appearance of light are important factors of buying environments that produce emotional effects in buyers and stimulate consumer activities. Lighting is one of the largest consumers of electricity in commercial buildings. Lighting controls by occupancy, daylighting, personal tuning, and institutional tuning offer significant energy savings. Another feature of commercial buildings is highly glazed spaces like atria in shopping malls. The glazed spaces look attractive but entail the cooling load in summer and heat loss in winter. Energy use and comfort issues should be addressed from early stages of building design.

Daylight contributes to both energy savings and occupants' well-being when it is well exploited. As the GlobalABC Roadmap for Buildings and Construction 2020-2050 recommends, target technologies for sustainable buildings are passive design strategies according to specific bioclimatic regions and specific building types, and integrative window design and control including orientation, shading, optimized material choices and harmonized electric lighting systems. But the building energy performance is significantly influenced by user preference and behaviour during the operation phase of the building. Correct understanding of user interaction with the building systems contributes to delivering required good performance as well as the comfort and healthy environment that meets user requirements.

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4 Occupancy and use of lighting systems

4.1 Simulation of occupancy

4.1.1 Introduction

Occupancy has strong impact on building use and performance. Most of the present building occupancy models are static and deterministic. They assume that the number of people staying in a building at a certain place and time is in accordance with an occupancy schedule following the function of the building. In real live a series of unpredictable, stochastic events like traffic, sickness, news from the outside and the inside of organization, etc., significantly change the occupancy.

A new method for occupancy prediction and simulation has been developed at LBNL by a team led by Tianzhen Hong (thong@lbl.gov). A new software, using an agent-based stochastic occupancy prediction model is available from: http://occupancysimulator.lbl.gov

The method is also well described in “Agent-based stochastic Occupancy Simulator” by Yixing Chen, Tianzhen Hong (∗), and Xuan Luo.

According to Yixing Chen, the Occupancy Simulator simulates presence and movement of each occupant by three types of events using three Building Simulation stochastic models:

(1) the status transition events (e.g., first arrival in office) with Reinhart’s LIGHTSWITCH-2002 model,

(2) the random moving events (e.g., from one office to another) with Wang’s homogeneous Markov chain model, and

(3) the meeting events with a new stochastic model.

To simplify the user input process, occupants with similar movement behaviours are grouped into an occupant type, and spaces with similar use patterns are grouped into a space use type. Furthermore, building templates can be developed that provide default assumptions of occupant density, occupant profiles (number and types), and space profiles (number and use types).

The simulated results represent three levels of occupancy schedules meeting most application needs:

(1) the whole building level (number of occupants),

(2) the individual space level (the number of occupants and the occupied status), and

(3) the individual occupant level (where, and in which space, a particular occupant is).”

4.1.2 Simulation of occupancy in the scope of Subtask A

In the scope of the Task A the occupancy pattern of one firm has been simulated. The company name is Elmarco and it’s located in Gdynia, Poland. The company occupies a restricted area (504 m2) on the first floor of a larger building. The number of employees fluctuates over time between 15 and 20. The plan of the first floor is shown in figure 1., this figure shows also screen shots with some input data.

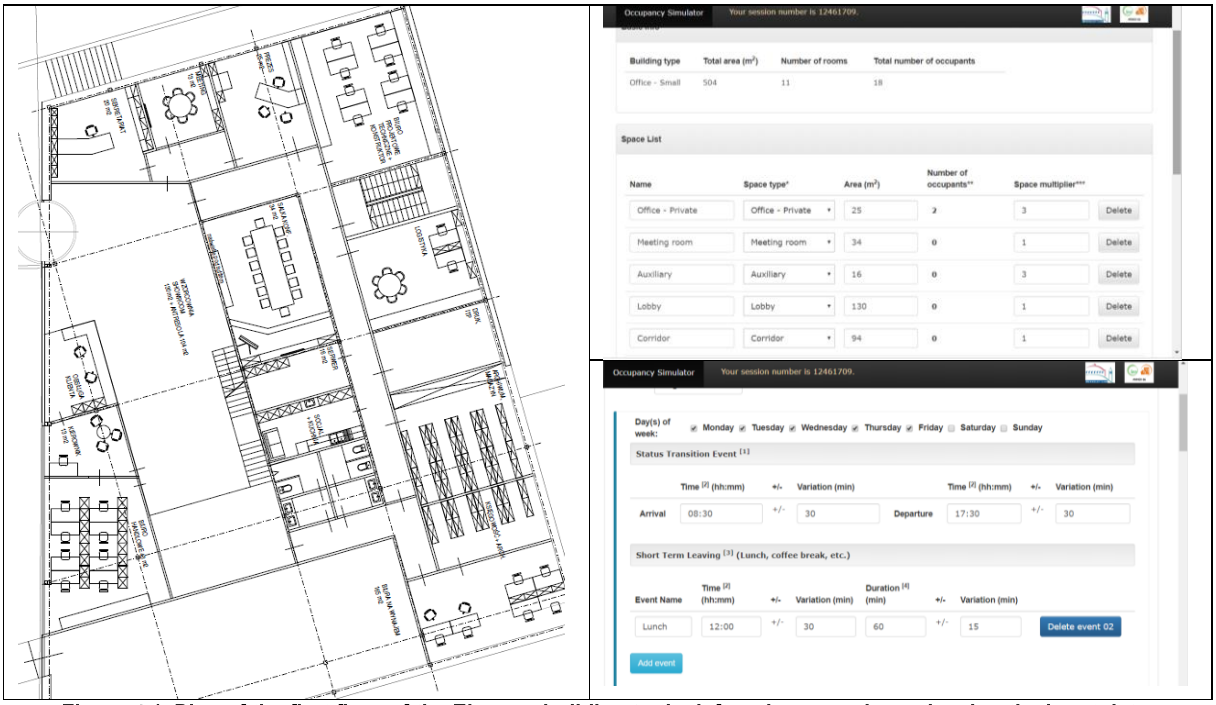

Figure 4.1. Plan of the first floor of the Elmarco building to the left and screen shots showing the input data.

In the figure 2., showing the results for a single room over one-month time, we may find many time intervals when minimum one of the employees is not present, it happens also that one of the employees is not present during the whole day.

A closer look at the figure 3., showing the results for this office for three days, gives even more interesting information. The start and the end of the working day marked by the presence of minimum one person is rather stable, but occupancy changes a lot. There are time periods when the room is empty, especially around the lunch time. We may also observe that the room is seldom occupied by all four persons.

Figure 4 shows the results for three days in January, this time for the whole building.

The simulator does not give possibility to add the building location, so the comparison between the occupancy and the access to daylight cannot be considered. In our case the location of the case study building is:

- Longitude: 18.5319°
- Latitude: 54.5189°
- Zenit: 90° 50

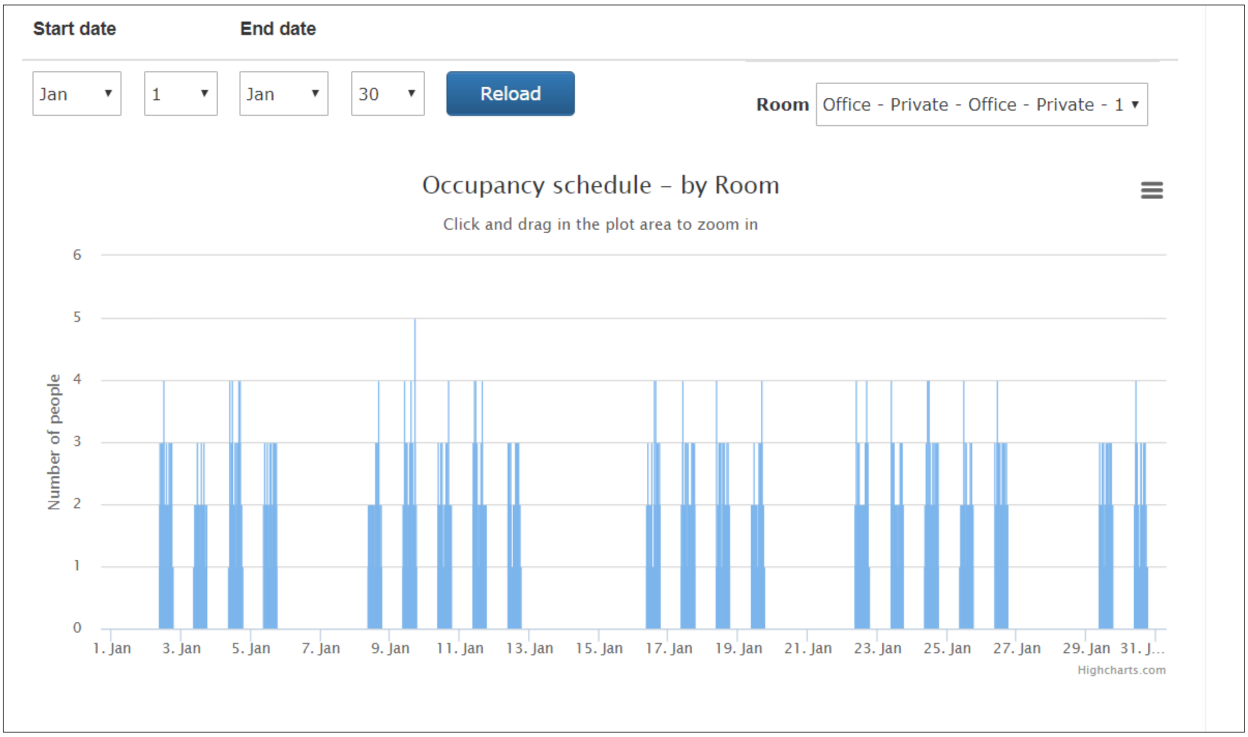

Figure 4.2. The results for a single room over the one-month time.

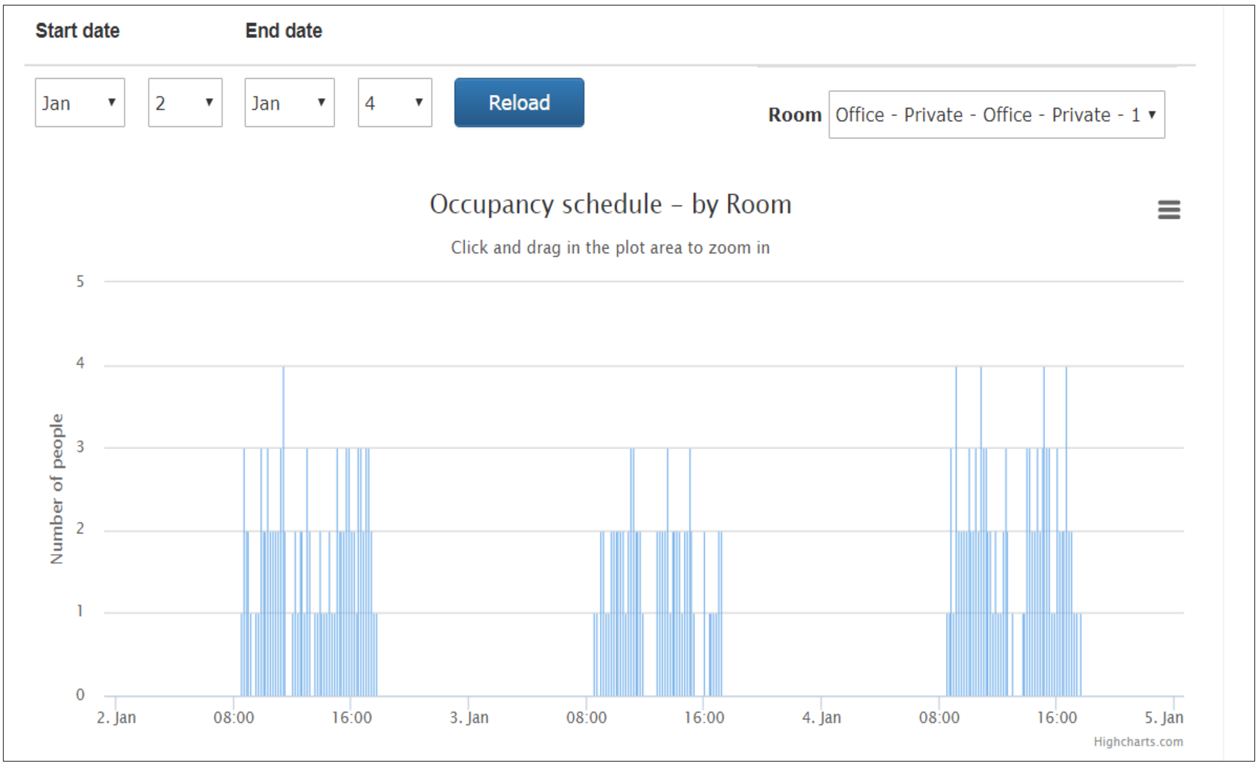

Figure 4.3. Results for a single room during three days in January.

We have compared the length of the day for the location with the occupancy results, see figure 4. It appears that the start of the occupancy coincides very well with the sunrise and that it stretches for minimum one hour after the sunset. The coincidence of the start of the working day with the sunrise tells that the daylight level is very low when the first person(s) enters the building, obviously those occupants need to switch electric light on. A preferable condition is when the daylight level at the start of the working day is high enough, so it does not trigger occupants to switch on the light. When it happens through the year is not possible to calculate without geographical data for the location and the information about the sky condition (clear - overcast).

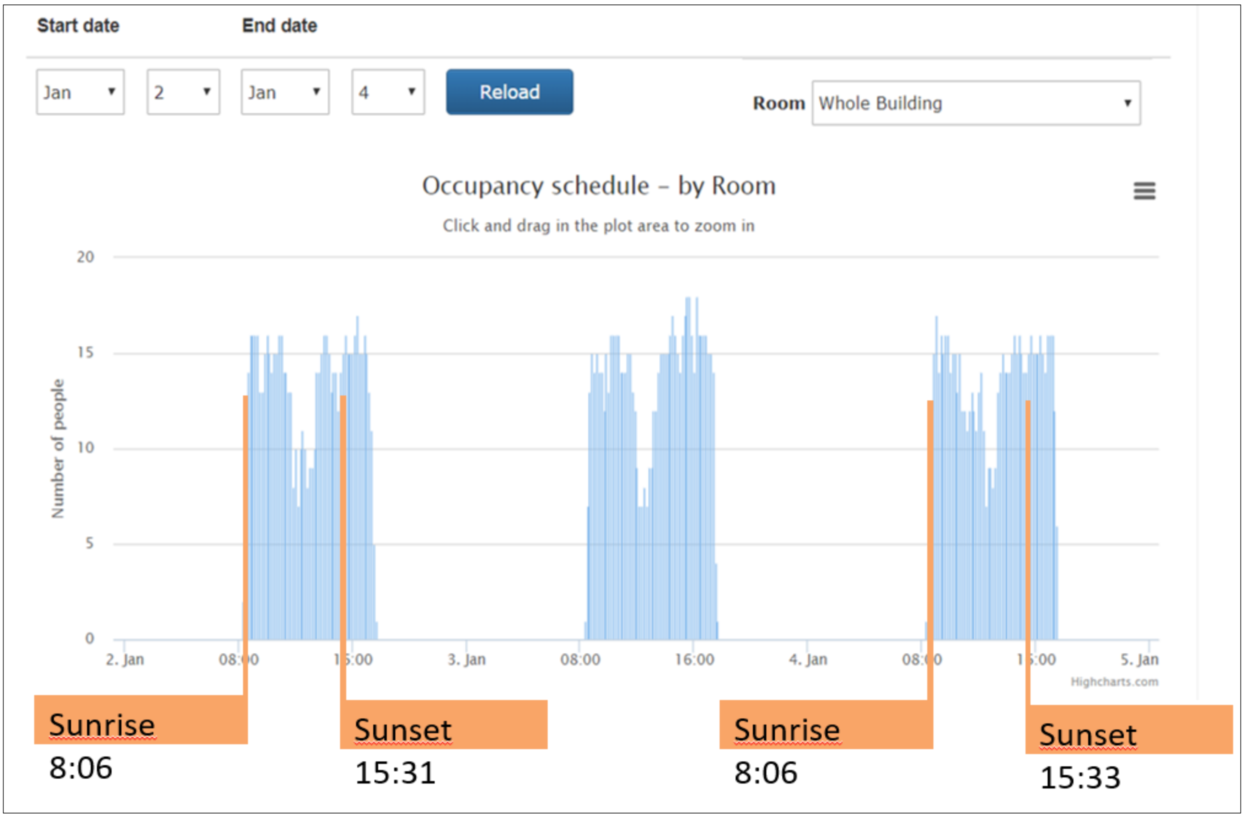

Figure 4.4. Results for a WHOLE BUILDING period 2 – 5 Jan.

4.1.3 Conclusion

The occupancy simulator seems to be a very good tool for occupancy calculations, but for lighting calculation purposes it needs to be connected to lighting simulation tools, which is not streit forward at the moment. However, we think that some simple questions, like the necessity of switching on-off the lighting at the start/end of the day could be answered if the program have been extended to include:

- buliding location (Longitude, Latitude)
- sky models occuring at the location and their probability across the year
- the calendar with estimated level of outdoor radiation (from sunrise to sunsets) for the sky models relevant for the location

The most serious concern is that the simulator is limited to one building type, that is office building. As we have many other building types in the project, we had to use the other methods, mostly the registration of the presence and the use of light in the respective buildings.

4.2 Registration of occupancy and use of lighting with a diary method

The diary method has its root in the time-geographical research from the 60s. The aim was to better understand temporal and spatial processes, including people's activities (Ellegård & Svedin, 2012). Over the years the method has been used in a multitude of different settings such as transportation and energy-related behaviour (Palm & Ellegård, 2011). The advantages of the method are that it includes all kinds of behaviours and do not need to rely on questionnaires. Furthermore, the participants don't need to reflect when marking their behaviour. The drawbacks are that the method is a burden for the participant and it is also quite time-consuming for the researcher regarding preparations, instructions and coding. However, it seems that the advantages are important and that it is a cheap and easy way to get information about behaviour.

Concerning the use of lighting and daylight a diary was developed by Maleeptiwan-Mattsson (2013). This method was investigated regarding its reliability and validity. The aim of the method was to be able to examine relationships between occupant-behaviours, occupancy and light on time. The results showed that there was a quite good correlation between the self-reported and logged data, r= .65 for activities regulating ceiling luminaires; r=.66 for occupancy vs. vacancy. This method has been used in the present study.

The participants were asked to report both movements and activities, Movements included: (i) coming into the room, (ii) sitting in the room, (iii) leaving the room but staying in the building, and (iv) going outside the building.

Activities that should be recorded were:

- regulation of a ceiling luminaire: (i) switch on, (ii) switch off, and (iii) do nothing (additionally, if relevant: (iv) increase and (v) lowering of lighting level with manual dimmers), regulation of a desk lamp: (i) switch on, (ii) switch off, and (iii) do nothing;
- adjustment of window blinds and/or curtains to block daylight from the office's windows: (i) 100 % blocked, (ii) 75 % percent blocked, (iii) 50 % percent blocked and 0 % percent blocked.

Each time a new movement or activity was performed, a new row on the diary was used, starting with the registration of time.

The time required for the data collection was 1 day at two different occasions.

	Movement	Activity			
Time	Location	Ceiling lamp		Desk lamp	Sun shade
	☐ Entering the room/workplace ☐ Sitting in the room ☐ Leaving the room but in build. ☐ Leaving the building	☐ Switch on ☐ Switch off ☐ Do nothing	☐ Increase lighting level ☐ Decrease lighting level	☐ Switch on ☐ Switch off ☐ Do nothing	☐ 100% ☐ 75% ☐ 50% ☐ 0%

Figure 4.5: Extract of the diary.

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4.3 Registration in Office building

4.3.1 Introduction

The RIAS Built Environment Control Lab was established thanks to the technical-scientific synergy of professors and researchers of the Department of Architecture and Industrial Design of the University of Studies of Campania “Luigi Vanvitelli”. In the Lab, teaching support activities, experimental studies and scientific research are carried out every day. The Lab provides services to other universities, local authorities, research institutions and industries, through tests and experiments in lab, in situ and simulation analyses. It includes two sectors: 1) Acoustics and vibrations, 2) Energy and lighting. The RIAS laboratory is located in Frignano (southern Italy, latitude 40°59'38.51"N - longitude 14°10'48.16"E). A multi-occupants office and a single-occupant office were used in this work; both the offices are located on the first floor of RIAS laboratory. The aim of the study is to register occupancy patterns and user’s behaviour in relation to lighting and shading systems.

Figure 4.6: The location of Frignano in the south of Europe.

Figure 4.7: The location of the office.

Figure 4.8: The façade of the building and the position of the offices that are included in this study.

The single-occupant office has three narrow windows oriented to the south and three narrow windows oriented to the west. All windows are equipped with double low-E glazing.

The multi-occupant’s office (Figure) is a large open space office located on the first floor of the laboratory. It has a large double low-E glazing window (size 8.0 x 2.0 m) oriented to the east and equipped with vertical blinds on the internal side. Ambient lighting consists of 3 ceiling fixtures, each equipped with two fluorescent lamps (2x 56 W).

In both offices, the ambient lighting and desk lamps can be controlled manually.

Figure 4.9: Interior view of the multi-occupant's office.

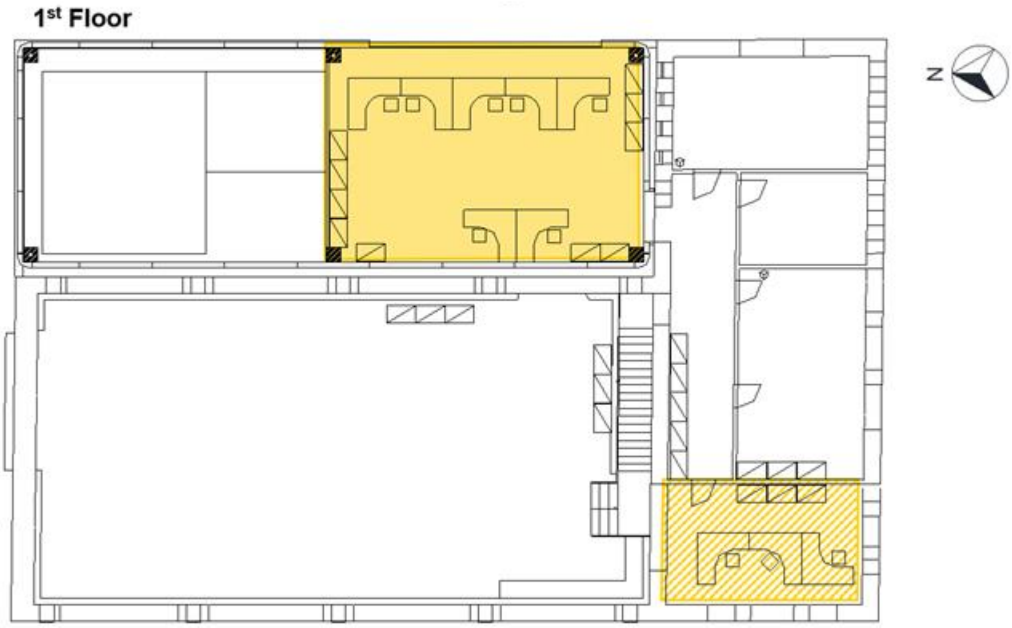


Figure 4.10: The position of the multi-occupant's office is highlighted with . The single-occupant office is in the dairy registration process, but it is not included in the measurement of illuminance values.

4.3.2 Methodology

4.3.2.1 Diary

The procedure followed before and during the registration day is described in Figure 4.11.

Preparation	Meeting with employees	Registration Day
• Visiting the offices and observing the lighting control system; • Updating the registration and consent forms base on the offices visit. • Measurement of illuminance values due to the Electric light	• Explaining the study's background, aim and procedure of the study; • Discussing the details in diary form and unclear points; • Agreement on the time and the location that forms will be delivered/collected.	• Install illuminance meters; • Have registration forms filled by employees and collect them; • Recording the illuminance values on the east facade, as well as on the multi-occupants office workstations during the working time .

Figure 4.11: Procedure before and during registration day

The diary form used in the study was developed at the Institutionen för arkitektur och byggd miljö at the Lund University; an extract of the diary used is shown in figure 4.5. In addition to the questions in the diary, additional information was collected about the type and power of luminaries, presence of blinds/curtains, number and position of people who are using the space and age category. That information is related to the occupation of the offices, switching of the luminaires and adjustments of the curtains. Each time a new movement or activity is performed, a new row on the diary has been used, starting with the registration of time.

4.3.2.2 Measurements

During the registration day, the real light availability outside and inside the multi-occupants's office was evaluated by acquiring the outside vertical illuminances and inside horizontal illuminances. Figure 4.12 shows a detailed view of the multi-occupant's office with the position of the participants (point S2 to S5) in the diary registration process as well as the lux-meters. In this study, both the diary registration and the illuminance values measurement were performed on 10/03/2020. The vertical illuminance values on the east façade were acquired by placing an illuminance-meter Konica Minolta T-10 (with cosine correction, measuring range from 0.01 lx to 300,000 lx and accuracy of ± 2 %) on the external surface of the window (point V1). The global light contribution (daylight + electrical light) inside the multi-occupants's office was evaluated by acquiring the illuminance distribution. The internal global illuminance distribution is evaluated through four illuminance-meters Konica Minolta T-10 (points H1 to H4) placed on the desks in a horizontal position at 0.71 m from the floor. Both the outdoor illuminance on the east façade, as well as the indoor illuminance values, were taken every 2 minutes. The figure also reports the location of the desks, the luminaires and the furniture.

Figure 4.13 reports the detailed view of the single-occupant office with the position of the participants (point S1) in the dairy registration process.

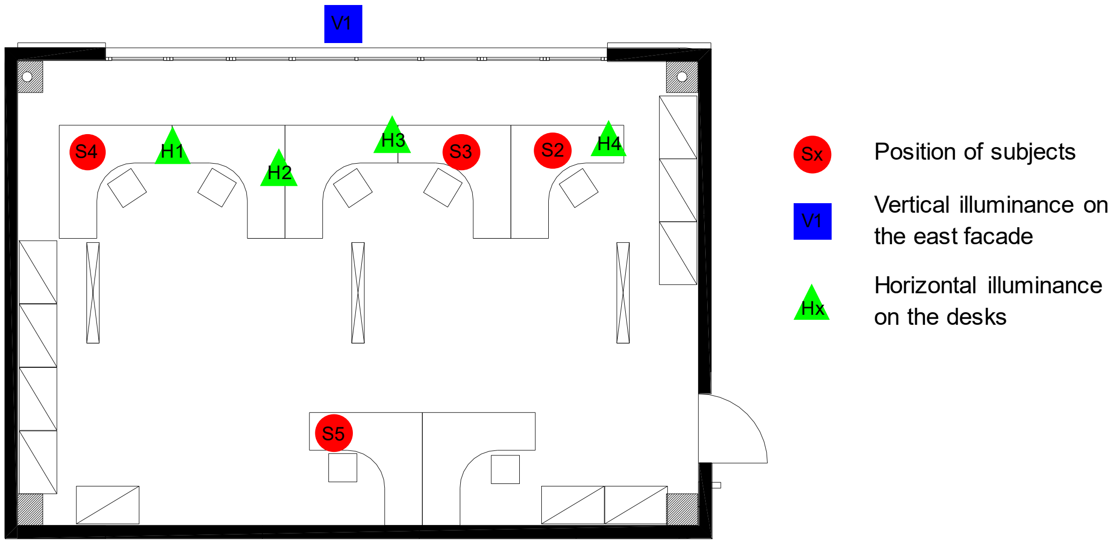


Figure 4.12: Detailed view of the multi-occupant office with an indication about the indoor illuminance values measurement points as well as the position of the employees.

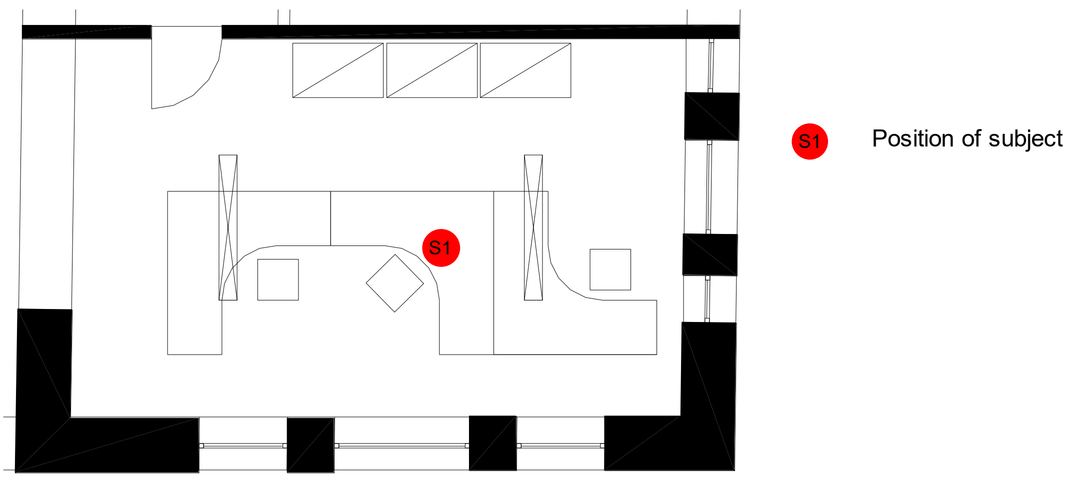


Figure 4.13: Detailed view of the single-occupant office with an indication of the subject's position.

In the multi-occupant's office, both the diary registration process and the measurement of illuminance values were performed. The users' movements and activity measurements were noted for the whole working period, while the global illuminance values were acquired every 2 minutes from 10:00 to 17:00. The electric light contribution was

evaluated in the days before the registration day, on each of the inside illuminance measurement points (points H1 to H4). The Daylight contribution was obtained as the difference between the global illuminance values recorded during the registration day and the Electrical light contribution.
The single-occupant office is included in the dairy registration process, but it is not included in the measurement of illuminance values.
The surfaces of the rooms and furniture were experimentally characterized by recording the reflectance values with the spectrophotometer Minolta CM – 2600d (size of integrating sphere: ø52 mm, wavelength range: from 360 nm to 740 nm and spectral reflectance: standard deviation within 0.1%). For every surface, the measurements were performed on three measurement points utilizing the standard illuminant D65, considering the Specular Component Included (SCI). The reflectance value on each measuring point was obtained as the mean value of three measurements, while the reflectance values of the surface used in the simulation software were obtained as the average value of the data recorded for three measurement points. The reference configuration of both offices is listed in Table 4.1.

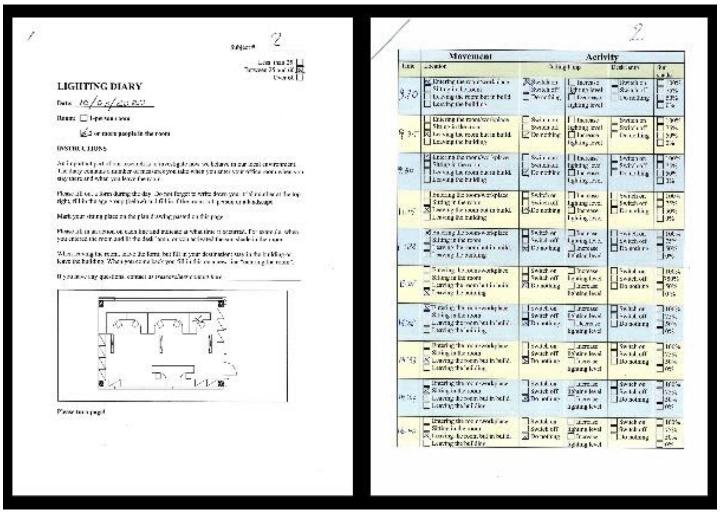
Table 4.1: Characteristic of the reference condition.

Characteristic	Multi-occupant's office	Single-occupant office
Office floor area	80 m^2	28 m^2
Ceiling height	2,6 m	2,6 m
South window-to-wall ratio	-	0,22
West window-to-wall ratio	-	0,22
East window-to-wall ratio	0,74	-
Ceiling reflectance	0,8	0,8
Walls reflectance	0,8	0,8
Floor reflectance	0,3	0,4
Luminaire	2 x 56 W fluorescent lamp	2 x 56 W fluorescent lamp
Number of luminaires	3	2

4.3.3 Results

4.3.3.1 Diary

The employees registered every change of the activity or movement in the diary. They also marked their location on the layout of the office, Figure 4.14. The data from the filled forms were extracted into Table .


LIGHTING DIARY

Movement

Activity

Figure 4.14: an example (multi-occupants office) of filled dairy form.

Table 4.2: An example (multi-occupants office) of extracted data from the dairy form.

ID subject	Time	Movement	Ceiling lamp	Dimming control	Desk lamp	Sun shade on	Outdoor light level (lux)
2	9:20	Sitting in the room	Switch on	No	Do nothing	0%	-
2	9:35	Leaving the room but in building	Do nothing	No	Do nothing	0%	-

2	9:50	Sitting in the room	Do nothing	No	Do nothing	0%	54701
2	11:15	Leaving the room but in building	Do nothing	No	Do nothing	0%	28011
2	11:22	Sitting in the room	Do nothing	No	Do nothing	0%	25132
2	13:05	Living the building	Do nothing	No	Do nothing	0%	9190
2	14:08	Sitting in the room	Do nothing	No	Do nothing	0%	9784
2	14:43	Leaving the room but in building	Do nothing	No	Do nothing	0%	9933
2	14:49	Sitting in the room	Do nothing	No	Do nothing	0%	9989
2	16:40	Leaving the room but in building	Do nothing	No	Do nothing	0%	6844
2	16:45	Sitting in the room	Do nothing	No	Do nothing	0%	4975
2	18:15	Living the building	Switch off	No	Do nothing	0%	-

Figure 4.15 shows the data listed in Table 4.2 for all participants involved in the registration process. The blue part of the diagram shows the time when the subjects are sitting in the rooms. The bar lines indicate the working hour in both the offices. As it can be seen from figures 4.15 and 4.16, the single-occupant office is occupied from 8:00 to 15:15, while the multi-occupant's office is occupied from 9:00 to 18:15. The figure 4.15 underlines that both offices are unoccupied from 13:00 to 14:00 due to the lunch break.

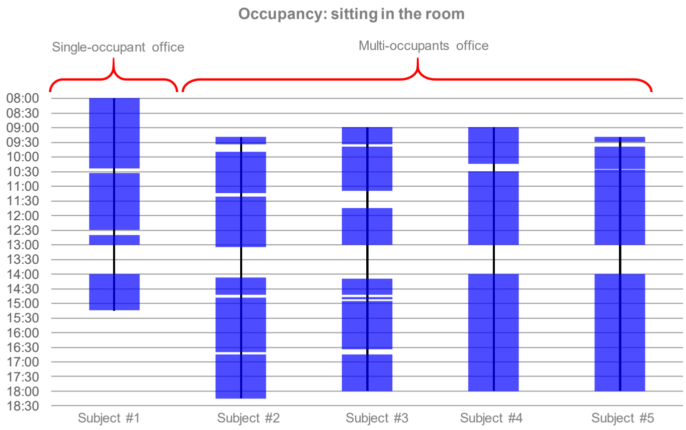


Figure 4.15: Diagram of the registered occupancy in both offices.

Figure 4.14 reports information about the operation of the ceiling lamps for both offices as well as the desk lamps and the shading system for the multi-occupants office. The working hours are indicated by black bars: 8:00-15:15 for single-occupant office and 9:00-18:15 for the multi-occupants office. For both offices, users switched on the general lighting at the beginning of the working hour and switched off at the end of the working day. In addition, the figure highlights that the vertical blinds are set aside for the whole working day.

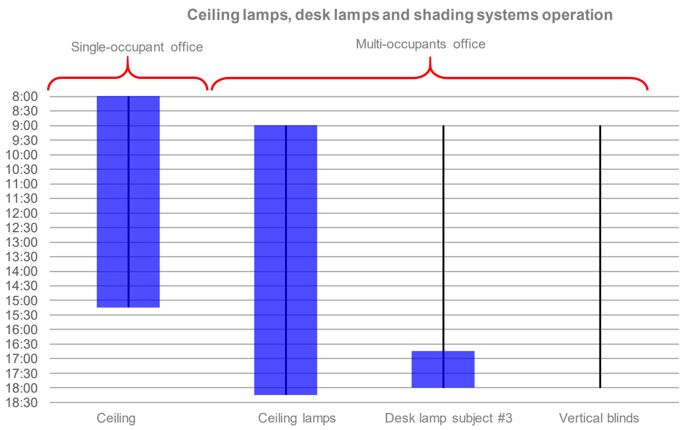


Figure 4.14: Operation of ceiling lamps, desk lamps and shading systems for both offices.

4.3.3.2 Illuminance on the Façade and inside the multi-occupant's office

The outdoor vertical illuminance values were acquired by placing a lux-meter Konika Minolta T10 on the external surface of the window oriented to the east, every 2 minutes from the 10:00 to 17:00.

Figure 4.15 shows the daylight illuminance values available on the external surface of the east oriented façade. According to the measurement points reported in figure 4.12, Figure 4.18a shows the horizontal global illuminance values (daylight + electrical light) acquired inside the multi-occupants office on the desk near the participants' workstation, while Figure 4.18b reports the daylight contribution only. Figure b underlines a different light distribution inside the multi-occupants office as a function of the measurement point. In particular, measurements highlight higher illuminance levels on measurement point #2 and #3 than those acquired on measurement points #1 and #4. In addition, from the figure it is possible to notice that the daylight illuminance values are lower than 500 lux on all measurement points from 11:30, because the office has only a window oriented to the east.

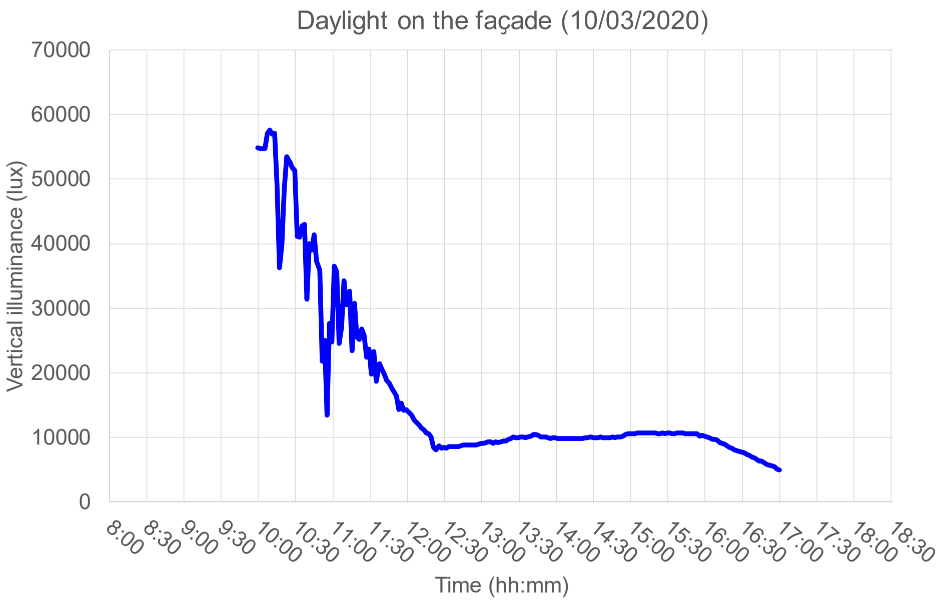
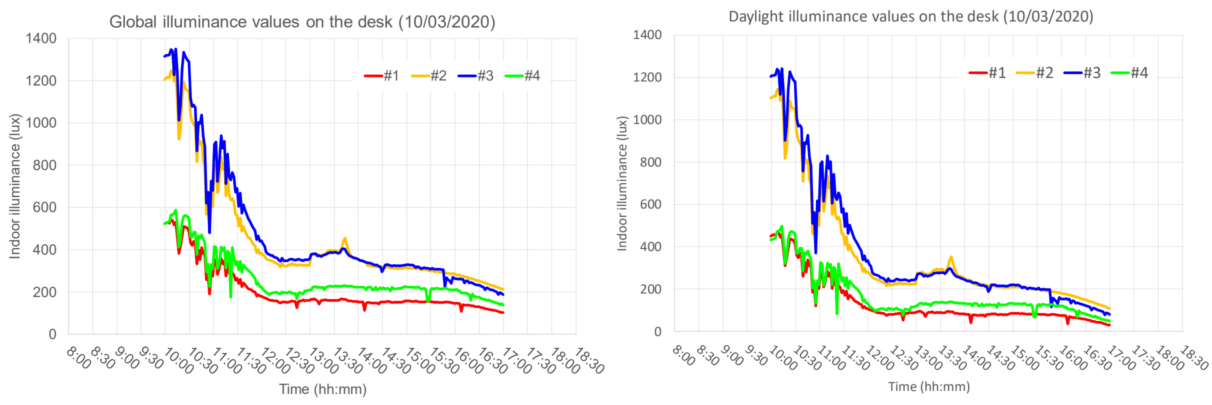


Figure 4.15: Daylight illuminance values on the façade east oriented



a) b)

Figure 4.18: Global illuminance values (a) and daylight contribution (b) on the desks of the multi-occupant's office acquire on 10/03/2020.

4.3.3.3 Diary V.S. measurements

In order to understand the user's behaviour, the results from the dairy forms are compared with the measurement in the multi-occupant's office. As Figure 4.19 shows, the change in general lighting is related neither to the outdoor nor to the indoor light level, even though light levels on the desks were higher than the recommended light level in offices (300 - 500 lux). The changes in the electrical lighting follow the time occupancy pattern of offices, not the light levels.

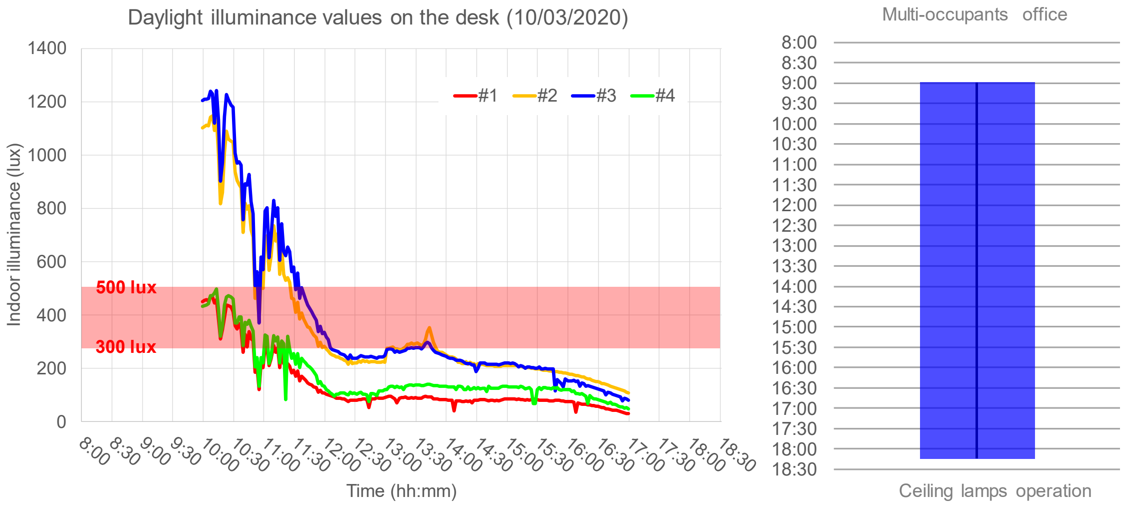


Figure 4.19: Comparison between the indoor light level and the operation of the ceiling lamps

Regarding the use of the vertical blinds in the multi-occupant's office, by comparing figure 4.16 withfigure 4.18b, it is possible to notice that also the relationship between changes in vertical blinds and indoor illuminance values is not considerable. In fact, whatever the illuminance values on the measurement points are, users do not change the position of the shading system. It could be because of the orientation of the window and the presence of buildings near the laboratory that limit the penetration of solar radiation, preventing the occurrence of glare conditions.

4.3.4 Conclusions

Finally, it appears that the daylight conditions in the multi-occupant's office create two different zones as a function of the users' position with respect to the window. The first zone near the middle of the window (measurement points #2 and #3) and the second zone on the sides of the window (measurement points #1 and #4). In the first zone, there is a higher availability of daylight, allowing to reduce the energy consumption associated with the electric light. In the second zone, the daylight levels are much lower than those recorded in the first zone, thus requiring a higher integration with electric light. The results highlight the need to improve the electric lighting system in order to guarantee the minimum recommended light levels inside offices. Considering the different daylight availability on the desks, a potential energy saving, compared to the current electric light usage, could be achieved by using a control system able to adjust the electric light contribution to the specific need for each user's position. In particular, the major benefits could be achieved by integrating the operation of ceiling lamps, desk lamps, shades and daylight in a comprehensive control strategy.

4.4 Registration in School buildings

4.4.1 Introduction

The *Singsaker skole* in Trondheim (63° N, 10° E), Norway, was selected for the study, due to historical relevance, well representativeness, and accessibility. The aim of the study is to register occupancy pattern and user's behaviour in relation to lighting systems. Both daylighting and electric lighting are included. The study was conducted in Feb 2020 by researchers from NTNU, department of Architecture and Technology.

The building was designed in 1913 as a primary school building, some restorations were done in 1942, 1958 and 1995. The school reopened as a primary school for 1-4 grades in 1995.

Figure 4.20: the location of Trondheim in the north of Europe.

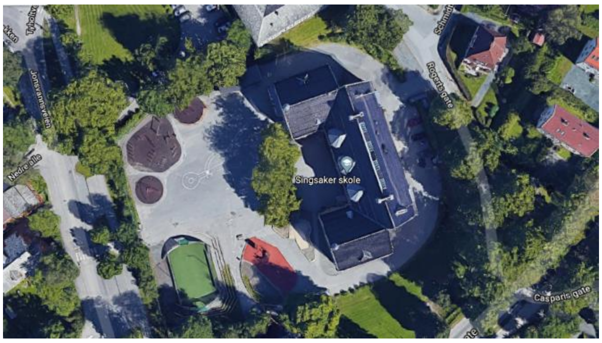


Figure 4.21: The location of the school.

Figure 4.22: The façade of the building and the position of the classes that are included in this study.

Figure 4.23: Interior view of the classrooms.

Although the building was built as a school at a time when the education methods were very different from the current ones, it still functions well as a learning space today. All classrooms have large windows with access to daylight. Windows are positioned rather high such that the students cannot see the outdoor landscape from the sitting position, their view is limited mainly to the sky. The windows are equipped with opaque fabric curtains having the visual transmissivity (Tn) of 1.3%. The classroom interiors were renovated during the past decades. The electrical lighting consists of pendant luminaires (56W) with fluorescent lamps for general lighting and separate fluorescent lamps for black boards. Some classrooms have manual diming system, but none of the classes that were included in this study had diming system and the only control method was switch on/off. The teachers are the led users, they have full control of the electrical light switching and decide how much the windows may be covered by the curtains.

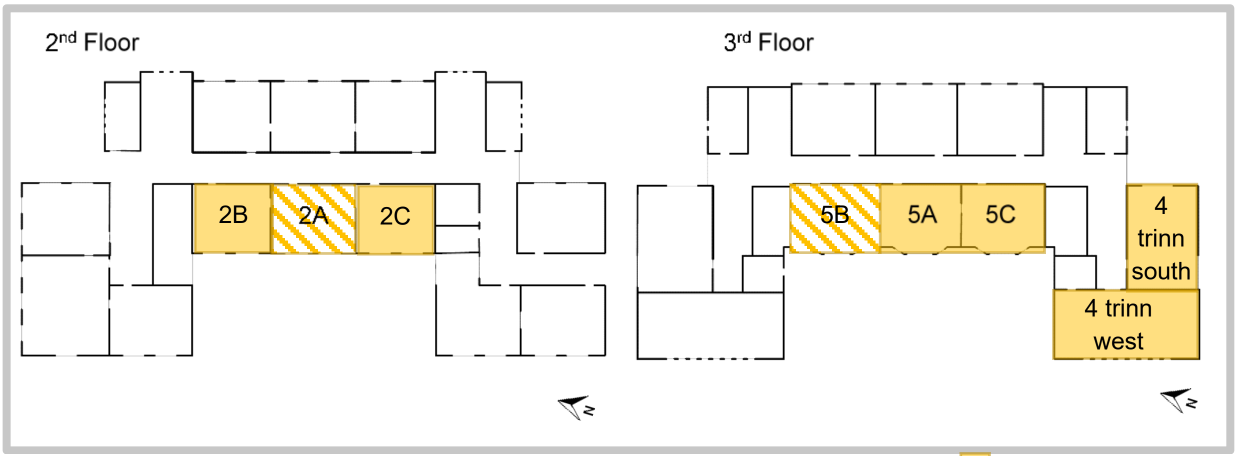


Figure 4.6: The position of the classrooms that teachers filled the forms are highlighted with . The classrooms 2A and 5B ( ) were not in the dairy registration process but they were included in the measurement of lighting metrics.

4.4.2 Methodology

4.4.2.1 Diary

The procedure followed before and during the registration day is shown in figure 4.25.

Preparation

- Meeting with the rector;
- Research about the background of the school;
- Visiting the classes and observing the lighting control system;
- Updating the registration and consent forms base on the school visit.

Meeting with teachers

- Explaining the study's background, aim and procedure of the study;
- Discussing the details in diary form and unclear points;
- Agreement on the time and the location that forms will be delivered/collected;
- Have consent letters signed.

Registration Day

- Have registration forms filled by teachers and collect them;
- Take pictures of the facade each 15 minuntes;
- Recording the changes in outdoor illuminance by lux-meter on the façade of the building every 15 mins. during the whole day.

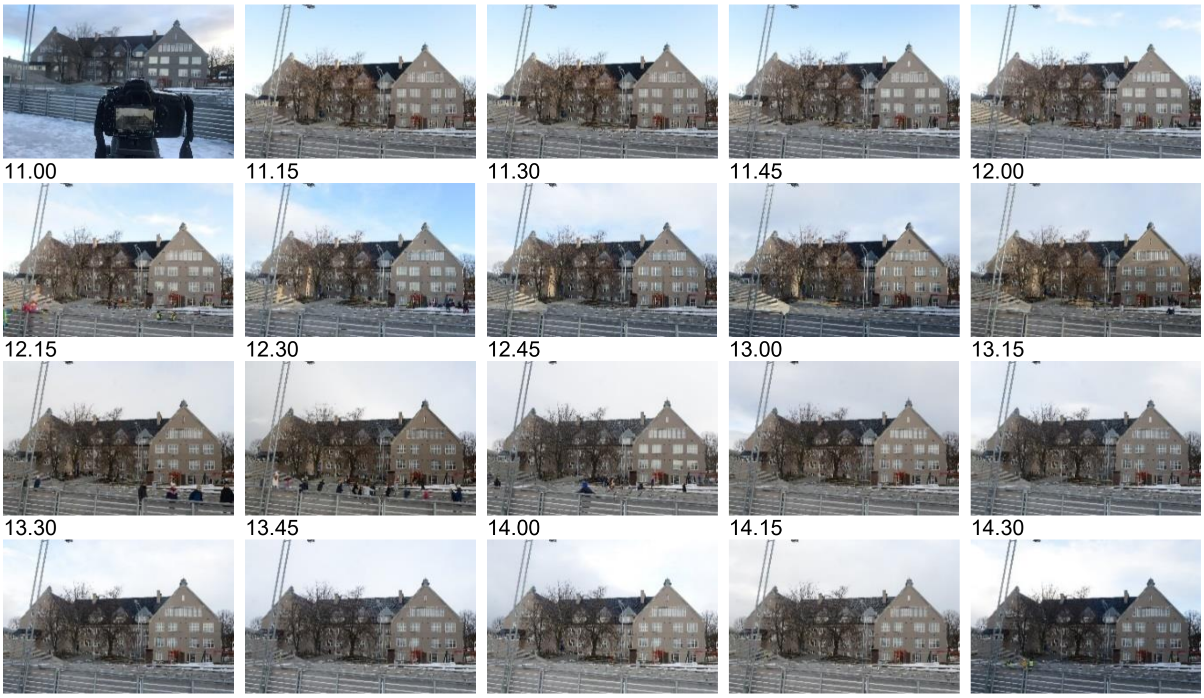
Figure 4.25: Procedure before and during registration day

The diary form used in the study, Figure 4.5, was developed at the Institutionen för arkitektur och byggd miljö at the Lund University. For the purpose of this study, it was slightly modified to consider the local conditions (type of luminaries, presence of projector, blinds/curtains, etc.). It collects participants' data (classroom number, age category, number of people who are using the space, etc.) as well as movements and activities. Those are related with occupation of the classroom, switching of the luminaires and adjustments of the curtains. Each time a new movement or activity is performed, a new row on the diary has been used, starting with the registration of time.
In parallel, pictures of the main façade have been taken each 15 min during the operating hours. They enable a check of the diaries' accuracy, e.g. adjustment of the curtains. These pictures are shown in table 4.3.

Table 4.3: Pictures of the school's facade from 8.30 to 14.30 during the registration day

8.30	8.45	9.00	9.15	9.30

9.45	10.00	10.15	10.30	10.45



4.4.2.2 Measurements

During the registration day, measurements of illuminance on the façade outdoors have been taken every 15 minutes in the same three positions on the façade. The measurement points have been chosen with care: not shadowed by trees or buildings and easily accessible, figure 4.26.

Figure 4.26: Measurements on the façade

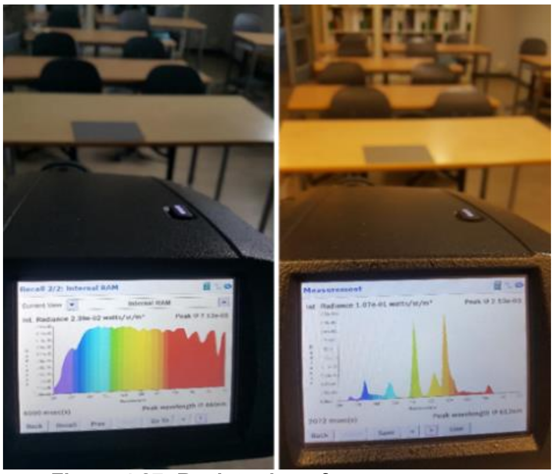


Figure 4.27: Registration of spectrum power distribution of lighting in space; daylight (left) and fluorescent lamp (right); by spectroradiometer.

In the classrooms, the measurements have been done between 11 am and 3 pm and for each classroom the measurements took around 30 minutes. For each type of measurements, three scenarios are considered: only Daylight, Daylight + Electrical Light and only Electrical Light. To create each scenario the curtain and electrical lighting on/off were used, in only daylight scenario the windows were 100% uncovered and curtains were aside also the electrical lighting was off, In the second scenario, the only electrical lighting, were measured while the curtains were 100% covered the windows to prevent the daylight, In combination of daylight and electrical lighting measurements were done in present of both electrical lights (lights were switch on) and daylight (curtains were aside). The HDR photography were taken from two positions representing the teacher and a student sitting in the back of the classroom, respectively. All measurements were repeated three times for higher precision. The illuminance on the working surfaces was measured with a luxmeter Hagner Model EC1, while Correlated Colour Temperature (CCT), Colour Rendering Index (CRI) and Spectrum Power Distribution (SPD) were measured using a spectroradiometer PR®-650 SpectraScan® Colorimeter PHOTORESEARCH. The CCT and CRI measurements, were performed in the middle of the classroom with the lens oriented toward a white neutral paper. To retrieve the data, the SpectraWin2 software was used.

Also, the light-technical properties of materials in classrooms were registered for use in Radiance and Diva. Finally, multiple photographs were taken from both student and teacher viewpoints to produce HDR images that enable a better understanding of the light distribution and the glare risk in the space.

4.4.2.3 Simulation

The simulations were carried out based on a 3D model of the school that has been built with Rhino 3D software. Lighting evaluations have been performed with Diva-for-Rhino plug-in and by using Grasshopper interface, figure 4.28.

In the same way as measurements, three lighting scenarios were considered for the simulations: only Daylight, Daylight + Electrical Light and only Electrical Light. For each scenario illuminance at each desk task positions has been calculated. Other metrics that also has been calculated on simulation were daylight factor and daylight autonomy.

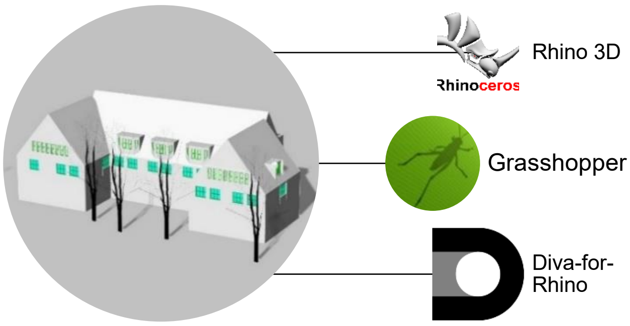


Figure 4.28: Software for model and simulation

4.4.3 Finding/Results

4.4.3.1 Diary

The teachers registered every change of the activity or movement in the forms. They also marked the location of their classroom on the layout of school, figure 4.29. The data from the filled forms were extracted into the tables, Table 4.4.

In the case a teacher forgot to register the time of an activity or a movement, and if was possible to detect the change from the outdoor photos of the facade, the table was corrected accordingly.

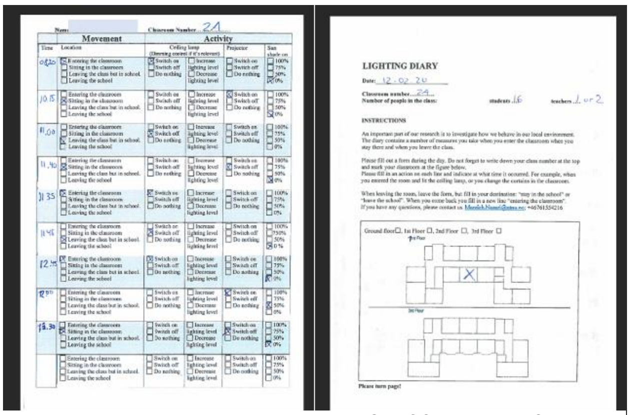


Figure 4.29: an example (class: 2C) of filled dairy form.

Table 4.4: An example (2C) of extracted data from the dairy forms. (the light level in outdoor is added later to the filled forms base on the measurements on the facade).

Total number of persons in the class	Number of students	Number of teachers	Time	Movement	Ceiling lamp	Dimming control	Projector	Sun shade on	Light level outdoor lux
17	16	1	8:30 AM	Entering the classroom	Switch on	No	Do nothing	0%	226
17	16	1	10:30 AM	Sitting in the classroom	Switch off	No	Switch on	100%	2330
17	16	1	10:45 AM	Leaving the class but in school	Switch off	No	Switch off	0%	2310
17	16	1	11:30 AM	Entering the classroom	Switch on	No	Do nothing	0%	3270
17	16	1	11:43 AM	Leaving the class but in school	Switch off	No	Do nothing	0%	3810
17	16	1	12:44 PM	Entering the classroom	Switch on	No	Do nothing	0%	3250
17	16	1	12:47 PM	Sitting in the classroom	Do nothing	No	Switch on	0%	2430
17	16	1	1:20 PM	Sitting in the classroom	Do nothing	No	Switch off	0%	4830
17	16	1	1:37 PM	Leaving the school	Switch off	No	Do nothing	0%	4100

The Figure 4.30 shows the data from table 4.4. The blue part of the diagram shows the time when general lighting, the projector or the sunshade is on. The bar lines indicate the working hour in the classroom (from 8:30 to 14:30). In this specific class (2C), the teacher started to use projector at 10:30 and then she switched off the general lighting and also covered the whole window with curtains, but in a similar situation at 12:47 even though the projector was used the teacher kept the general lighting on and the windows were not covered.

For the comparison, the following diagrams, Figure 4.31, shows the user's behaviour regarding the use of electrical lighting in different classrooms. The working hours of the school presented by black bars indicate 8:30-13:30 for classes 2A and 2C and for others 8:30-14:30. All of the classes switched on the general lighting at the beginning of the day, the light was switched on and off few times during the day, and switched off after the working hours, except 2A where the electrical light had remained on during the night. In this study it happened for one among 6 classrooms.

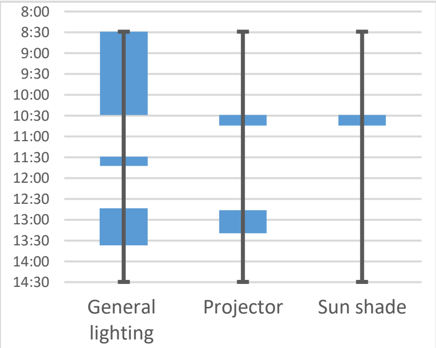


Figure 4.30: Diagram of registered activities by teachers in 2C-classroom from the dairy forms.

So, by extending this to the whole school building we may expect that in the absence of an automatic control, 17% of the classrooms keeps the lighting on after working hours, which is an unnecessary electrical lighting energy use in the school.

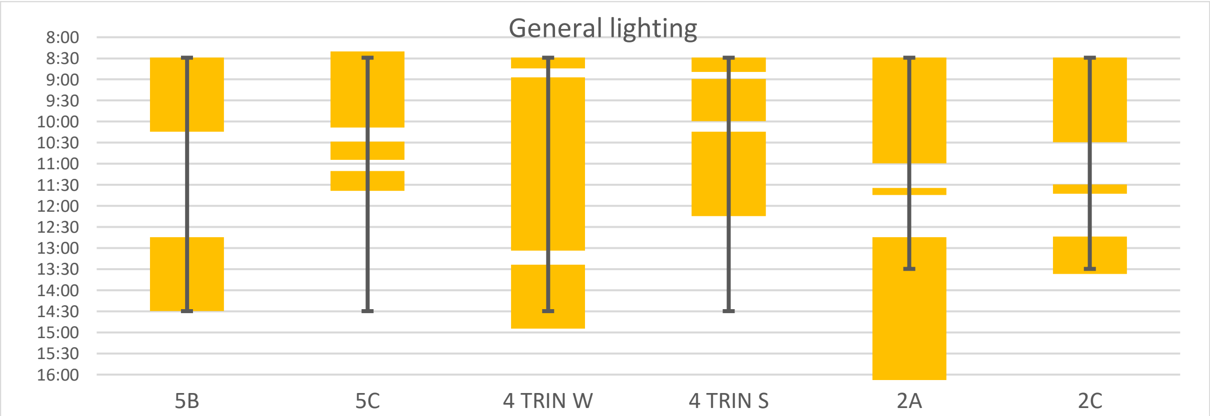


Figure 4.31: The time that general lighting in the classrooms is switch on, retrieved from the dairy forms.

As it is showed in Figure 4.32, the curtains in most of the classes were not changed during the day except of classroom "4 trinn west". The reason for this is probably the layout of the classroom, figure 4.24. In this classroom the board is located on the opposite wall to the windows, and it seems that teachers keep the curtains on to avoid glare and avoid frequent changing of the curtain position. The percentages in the legend show the part of the windows that are covered by curtains. 0% means that the curtains are totally aside and 100% is when the whole windows are covered.

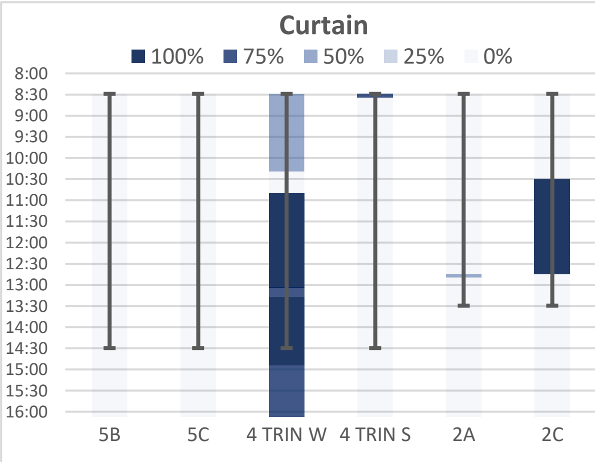


Figure 4.32: The time that curtains are used to cover the window.

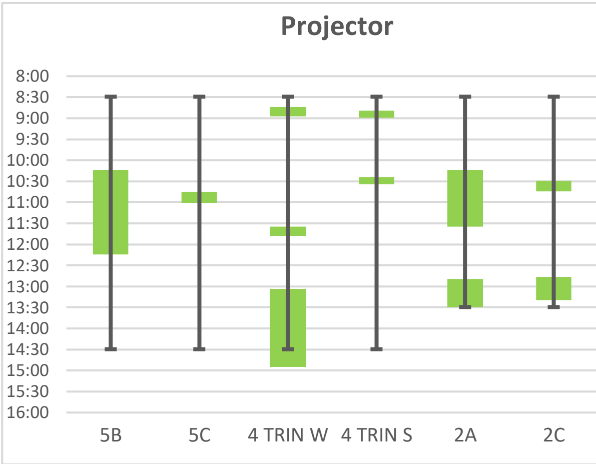
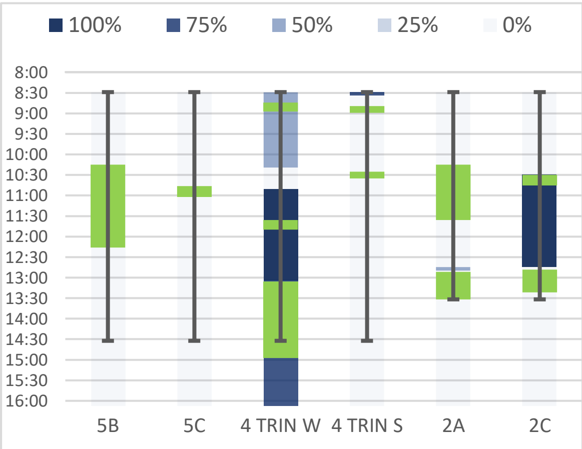
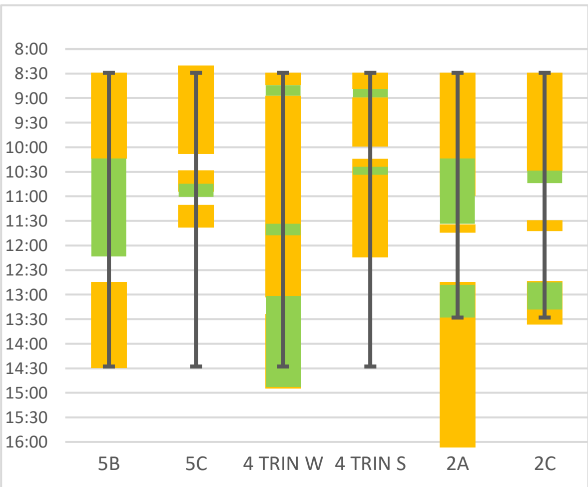


Figure 4.33: The time that projectors are used in the classrooms.



Curtains vs projector: In figure 4.34 the curtains condition (blue) and the time that projector was used (green) are shown. The only class that coverred the windows when they started to use the projector is class 2C but even in this class after the projector was switched off the window was still 100% covered. The reason for this is probably the low light level outdoors. In winter time the daylight does not reach to the standard level that is needed on the task position so keeping curtains open or close does not make a difference on neccecity of using electric light.

Figure 4.34: The time that curtains and projectors are used.



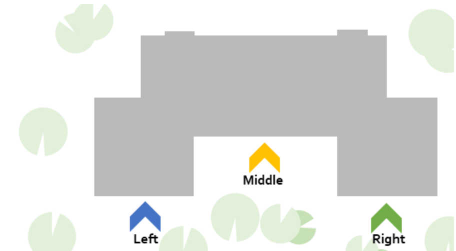
Genral lighting vs projector: figure 4.35 shows the time that general lighting is on with orange and when the projector is in use with green color. From the figure it appears that the general lighting is switched off during the time when projectors are used during the morning. After the main break, at around 12:30, this patterns had changed and although the projectors are used, the general lighting is still on.

Figure 4.35: The time when the general lighting (yellow) and projectors (green) are used.

4.4.3.2 Measurements

Façade illuminance:

The measurements of the illuminance on the façade show that the maximum light level outdoors was registered at 12:30 and the minimum at 8:30 at all the tree positions.



	Left	Middle	Right
Max (lux)	11250	8100	10090
Min (lux)	284	226	291
Mean (lux)	3767	2760	3498

Table 4.5: The maximum, minimum and mean amount of illuminance on facade for each measurement location.

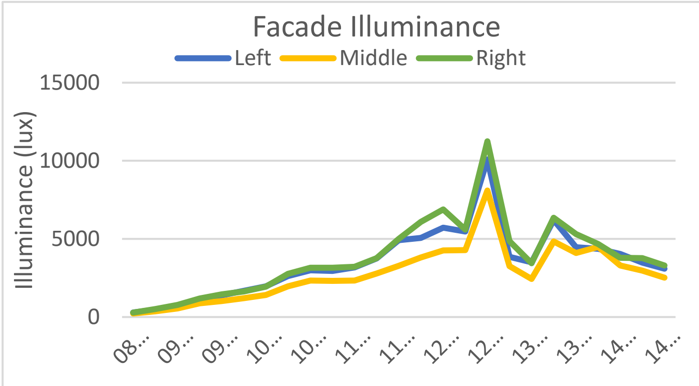


Figure 4.36: Facade illuminance during the registration day.

Illuminance mapping:

The light level on all the task places for three scenarios Daylight, Daylight + Electrical Light and Electrical Light are presented in figures 4.37 – 4.39 for Figurethe classroom (2C).

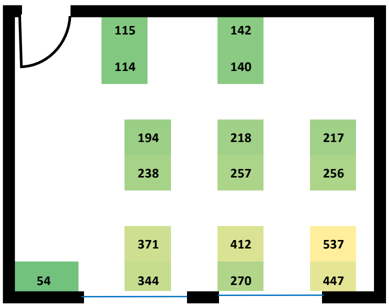


Figure 4.37: Illuminance values on task area (only Daylight)

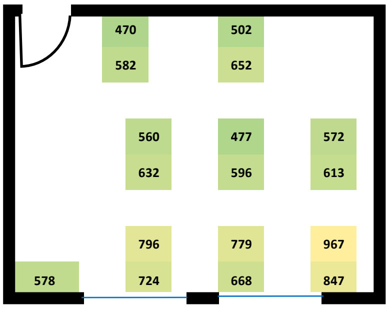


Figure 4.38: Illuminance values on task area (Daylight + Electrical light)

Figure 4.39: Illuminance values on task area (only Electrical Lighting)

In figure 4.40 a number is assigned to each task area. These numbers are listed in figure 4.41 to enable an easy comparison between light level at each task area in the different scenarios (Daylight, Daylight + Electrical Light, Electrical Light).

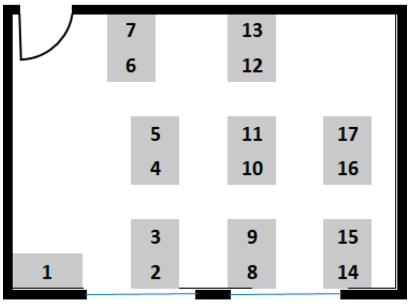


Figure 4.407: Task areas with assigned numbers.

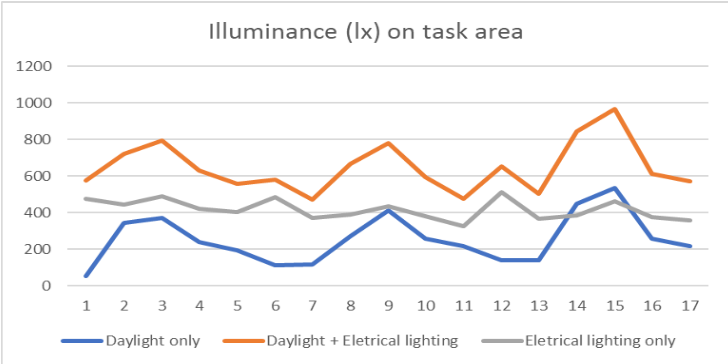


Figure 4.41 Diagram of task light level on each task area in 3 scenarios.

Correlated Color Temperature (CCT) and Color Rendering Index (CRI):

Figures 4.42 and 4.43 show the CCT and the CRI in the studied classrooms, respectively. The electric lighting, as expected, has the lowest CRI values. The lamps with higher CRI are recommended specifically because in the trines 1-4 students have art activities with frequent use of colored work devices (pencils, paint and others) in most of the classrooms. Providing better CRI can improve the learning experience.

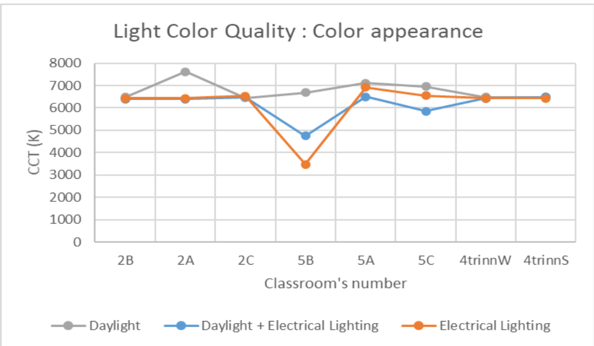


Figure 4.42: CCT

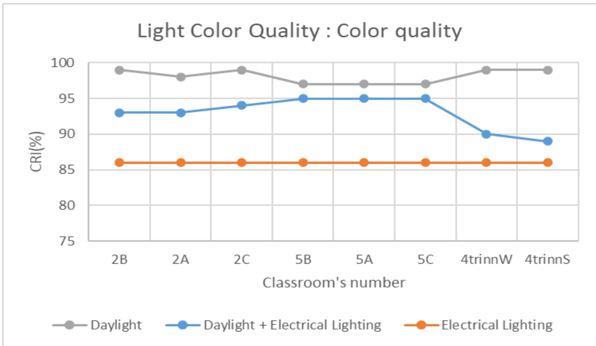


Figure 4.43: CRI

HDR images: figures 4.44 and 4.45

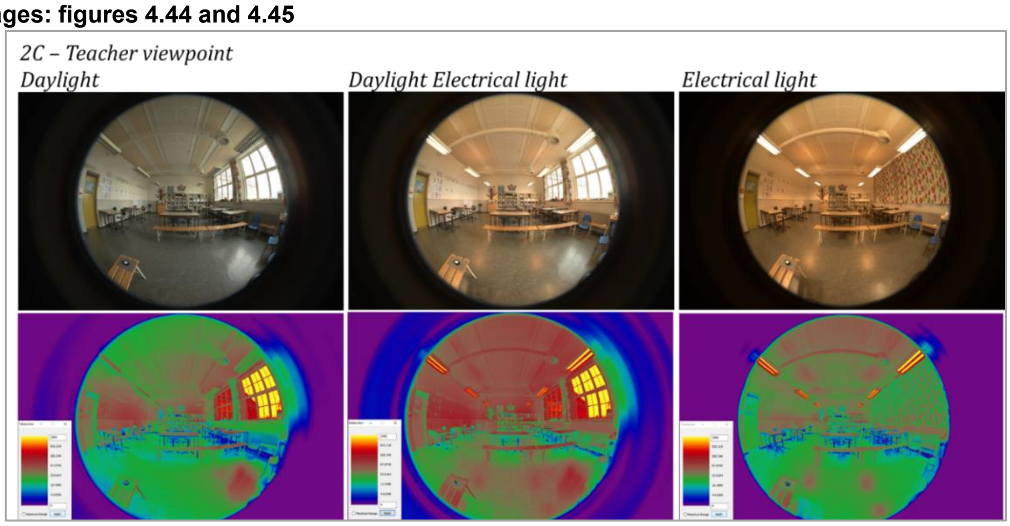


Figure 4.44: The teacher viewpoint for Daylight, Electrical Light, DL+EL in classroom 2C.

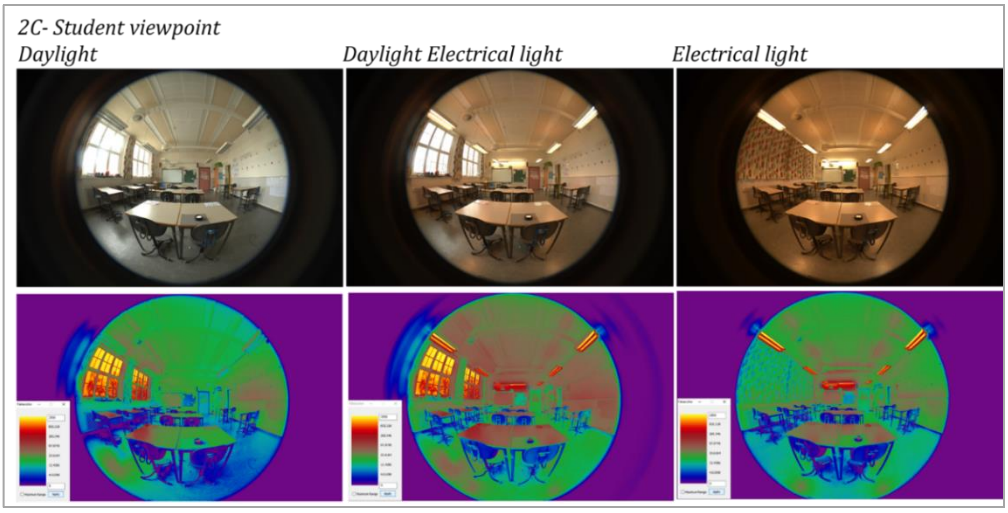


Figure 4.45: The student viewpoint for Daylight, Electrical Light, DL+EL in the classroom 2C.

As expected, the uncovered windows and the luminaires are both the potential sources of glare, both for students and a teacher. In this case the HDR photos were made in an overcast day in February with a daylight level outdoors of about 8500 lux, the luminance of the window glass has maximum 2430 cd/m2, which is an acceptable level in a room with an average adaptation luminance of about 60 cd/m2 (green). The scenario with both daylight and electric light seems to be best, as the average luminance in the visual field is highest 6150 cd/m2 with an average luminance about 100 cd/m2 which means better tolerance for bright points and surfaces.

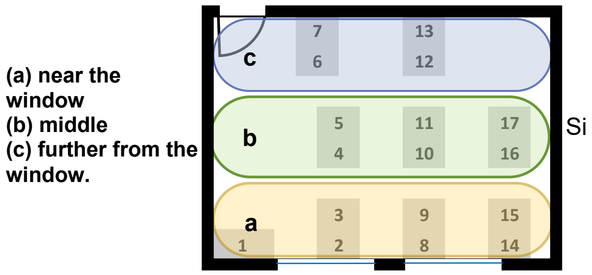


Figure 4.46 Position of task area and the zones:

First, results for the simulations of illuminance on task positions are presented for the classroom 2C. Figure 4.46 shows the location of these positions. Figure 4.48 indicates the illuminance for each position in the classroom at noon for different days in the year: the registration day (12/02), the winter solstice, the summer solstice, and equinoxes. Figure 4.47 indicates the illuminance uniformity in the classrooms for all the task positions.

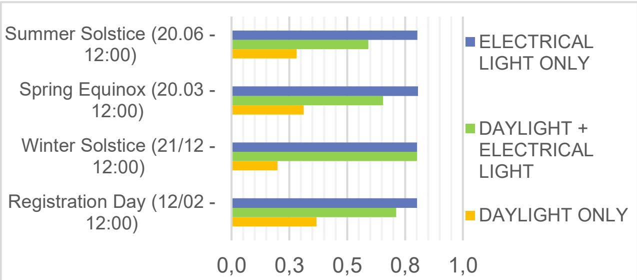


Figure 4.47: Classroom 2C - Illuminance uniformity

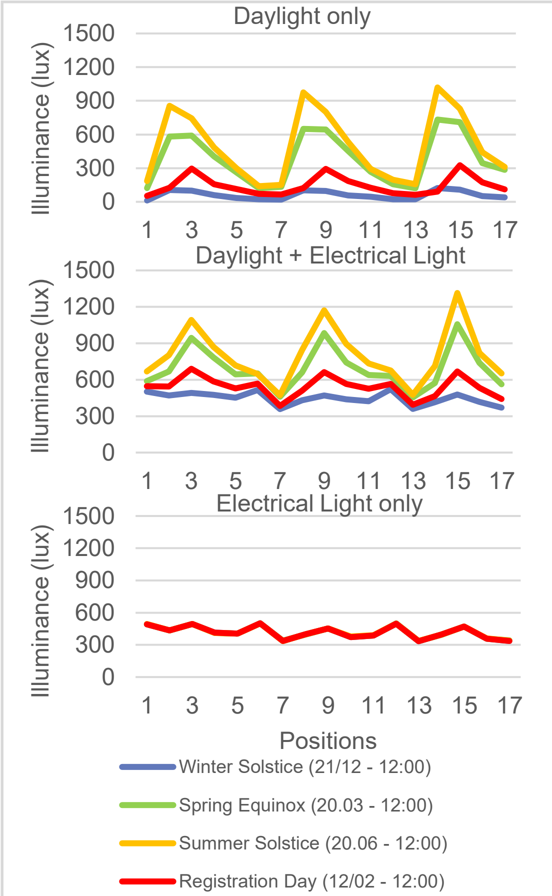


Figure 4.48: Class 2C- Illuminance on task positions

Finally, Figure 4.49-4.51, demonstrate daylight and electrical light and having more daylight on task positions which are the closest to the openings are obvious. Then, it decreases as moving towards the opposite wall. Still, by using only daylight, the 300-lux level is not achieved during winter specially in zone b and c. But in spring and summer, the level is easily reached on the task positions closed to the windows (zone a). For electrical light only, as the curtains are very opaque, the illuminance is constant, regardless the time of the year and during winter, it provides more than 300 lux on each task positions.

When daylight and electrical light are combined same trend is observed but the use of artificial lighting enables more illuminated task positions and some uniformity. This is confirmed in figure 4.47. Indeed, for daylight alone, the illuminance uniformity varies only from 0,20 to 0,37 whereas for electrical light only, the uniformity achieves 0,80. Then, for the combination of daylight and electrical light, the illuminance uniformity reaches 0,59 to 0,80.

On the registration day (12 Feb.), daylight alone cannot ensure enough illuminance on almost every task position for the entire day, figure 4.49. But again, electrical lighting provides a comfortable level of illuminance in the space. As seen in figure 4.50, during winter solstice, at no time 300 lux illuminance is achieved. During summer solstice and spring equinox, the 300 lux-level is reached during some hours, but it is not ensured all day long. Figure 4.51 shows that, together, electrical light and daylight provide enough light during all the occupied hours.

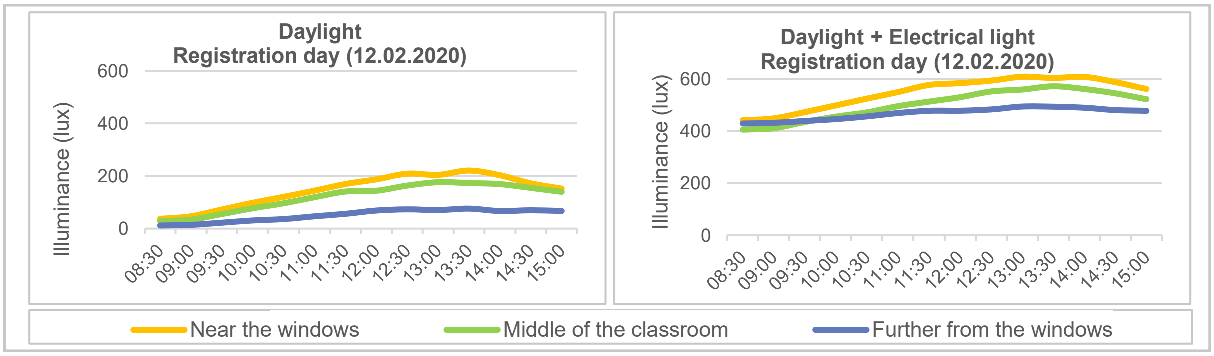


Figure 4.49 Registration Day, illuminance on task position Daylight (left) and Daylight + Electrical light

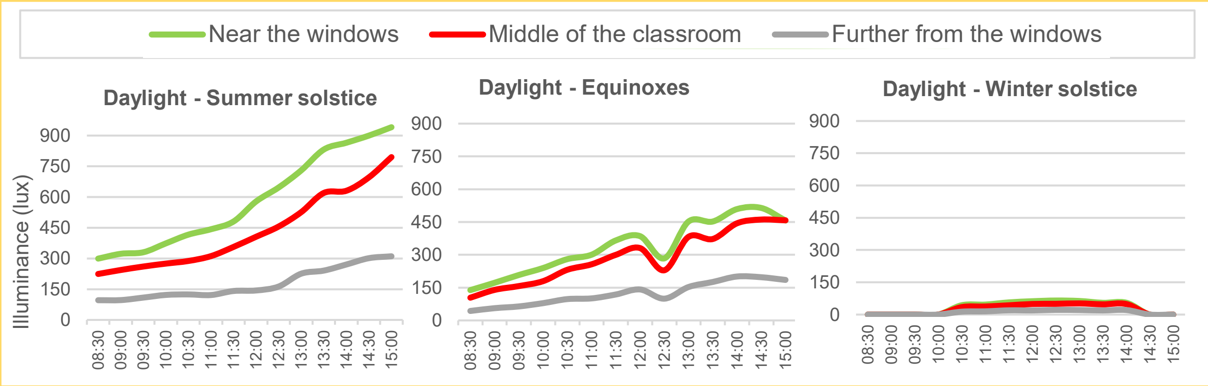


Figure 4.50: Daily evolution of the illuminance on task positions – Daylight only

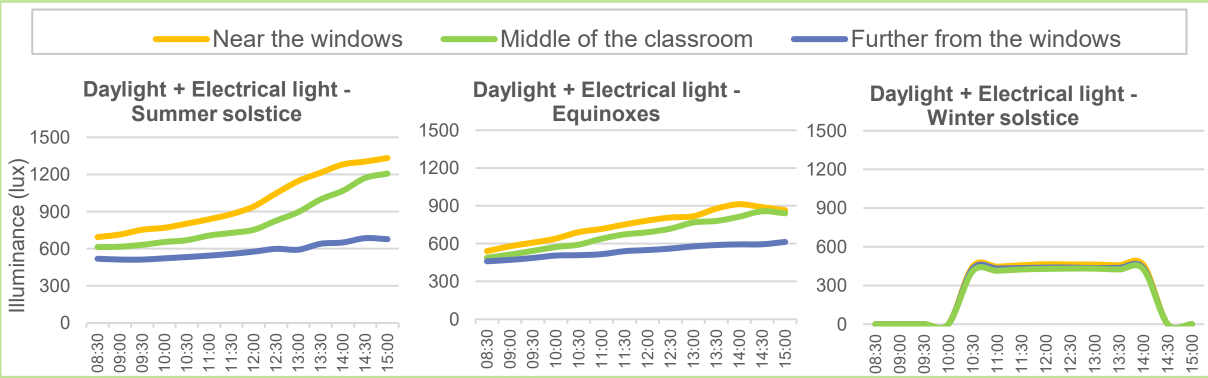


Figure 4.51: Daily evolution of the illuminance on task positions - Daylight + Electrical light.

Figures 4.52 and 4.54 present the simulation results obtained for the daylight factor in Singsaker primary school for both the 2nd and 3rd floor of the building. As expected, the daylight factor is highest closest to the windows. Its value varies from 0% in the corridors to over 5.0% near the windows. The mean daylight factor in classrooms varies from 2.24% to 3.60% (2C lowest and 4-trinn S highest). In the classroom 2C on the second floor the mean daylight factor is 2.29% and, in the classroom, 5B, on the third floor, the mean daylight factor is 3.31%.

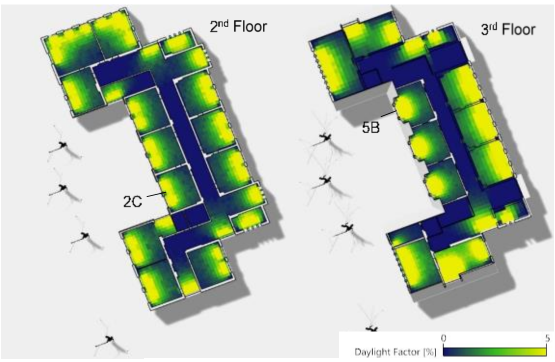


Figure 4.52: Daylight factor

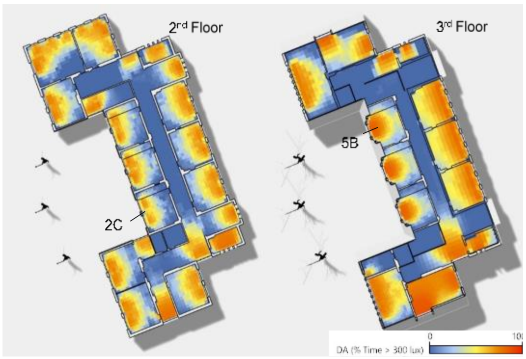


Figure 4.53: Daylight Autonomy

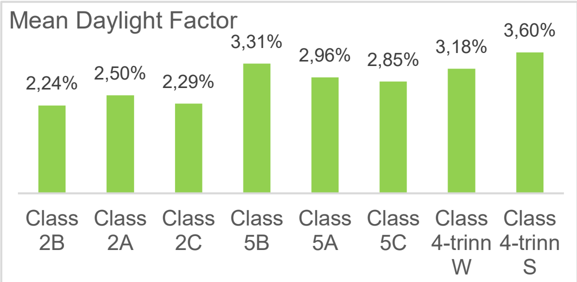


Figure 4.54: Mean Daylight factor values.

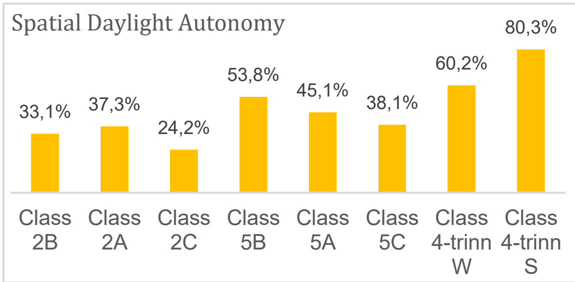


Figure 4.55: Spatial Daylight Autonomy values.

The Daylight Autonomy in the classrooms of the school is indicated in figures 4.53 and 4.55. The official occupied days and hours of the school are considered (from 8.30 to 14.30 without holidays). More specifically, in the classroom 2C, 24.2% has the lowest and in classroom 4-trinn S has the highest sDA value with 80.3% of the floor area that receive at least 300 lux for at least 50% of the annual occupied hours.

4.4.3.3 Discussion

4.4.3.3.1 Diary V.S. measurements

In order to understand the user's behaviour, the results from the dairy forms are compared with the measurements in the classrooms. As figures 4.56 and 4.57 show the changes in general lighting is not related to the outdoor light level. Since the light level in the registration day in most positions were lower than the recommended light level in classrooms (300lux), teachers kept electrical lighting on even at the time that light outdoor was at peak. The changes in the electrical lighting follow the time occupancy pattern of classrooms not the outdoor lighting condition at the registration day.

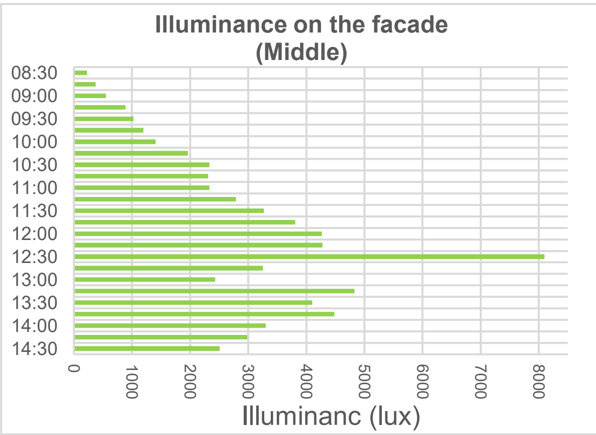


Figure 4.56: Illuminance on the facade (Middle)

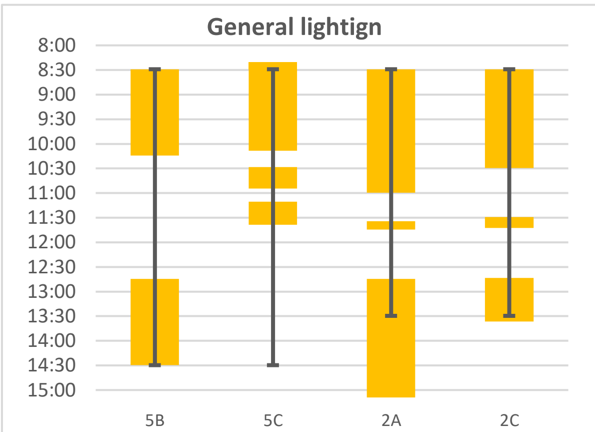


Figure 4.57: General lighting on the classrooms that are in middle of the facade.

To consider the relation between use of curtains and the projector the class "4 trinn west", which recorded most changes, was selected. The classroom is located on the right side of the façade. As it was mentioned before in the case of this class also the relation between changes in curtains or outdoor illuminance is not considarable and it confirms that this changes are mainly for prevention of glare on the board. Although as it is seen in figure 4.59 and 4.60, at 13:51 the projector is switched on after few minutes the curtains were changed from 75% had to 100%.

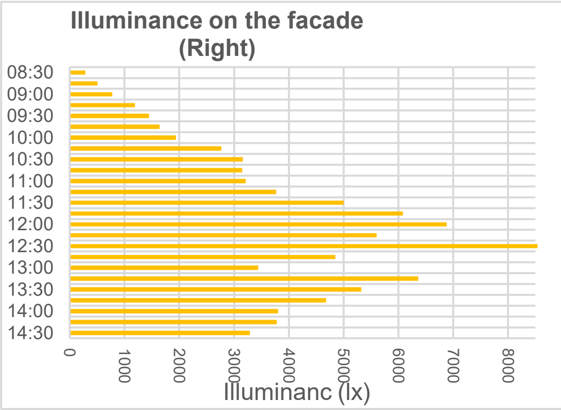


Figure 4.58: Illuminance on the facade (Right)

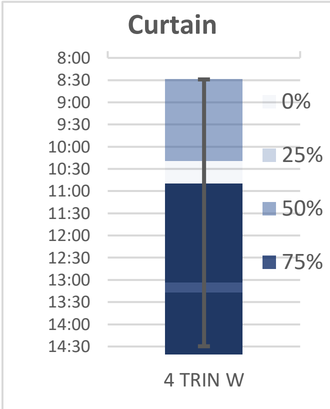


Figure 4.59: Situation of curtains in the class "4 trinn west" that is in the right side of the façade.

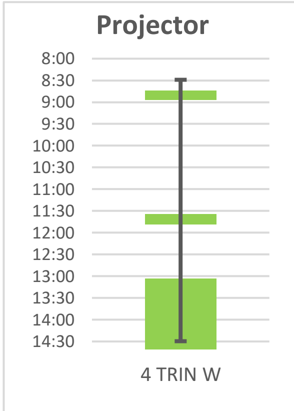


Figure 4.60: Changes in on/off projectors in 2 trinn west.

The 4. trinn classroom, oriented west, has different lay-out than the other classrooms. Indeed, the windows are facing the board and the students have their back towards the windows as seen in Figure 4.61. Moreover, windows are narrower, and the number of windows is larger. The results from the diaries show that the curtains are more used in this classroom. From 10:51 in the morning and especially each time the projector is used, the curtains are closed from 50% to 100% of the glazing surface. During the afternoon, when the sun is further west, the sunshades are entirely obstructing the openings.

Figure 4.61: Pictures of the class 4. trinn west in the afternoon (21.02.2020)

4.4.3.3.2 Evolution of the users' behaviour according to the time of the year

First, during winter, because of the late sunrise, the electric lighting is necessarily used at the beginning the of the school's opening hours and also due to Nordic sun characteristic during the winter the electrical lighting keep on all day.

The registration day took place during wintertime. As the illumination provided by daylight was low all day long, we were not able to determine whether users are switching off electrical lighting according to daylight level. We can suppose that they will do it when an adequate level of daylight will be reached on all task positions (illuminance of minimum 300 lux for example).

Then, concerning the classroom 2C, the results from the simulations for the winter and summer solstices as well as for the spring equinox show that, regardless the time of the year, task positions further away from the windows are not enough illuminated (inferior to 300 lux) when only daylight is provided. Therefore, the same behaviour as during the registration day is to be expected: use of both daylight and electric lighting. However, it may lead to high illumination values (superior to 1200 lux) on task positions illuminated with daylight only (some positions near the windows and in the middle of the classroom). Thus, the illuminance uniformity (U_0) recommended by the European Standards (EN-12564-1) of 0.60 is not achieved all along the year when only daylight is considered. When daylight will provide too much illumination on task positions closed to the windows but not enough on task positions in the rear part of the classroom, the illuminance distribution will not be comfortable for the occupants and therefore it can be expected that the curtains will be closed allowing better uniformity between all the task positions. It could happen notably during summer.

Concerning the lighting and curtains adjustments made when the projector is used, as it was already the case during the registration day (in February), it can be expected that the users would favour closing entirely the curtains and using the electric lighting, regardless the time of the year.

4.4.3.3.3 Predicting other classrooms

The same behaviour as described for the classroom 2C is to be expected in classrooms 2A, 2B, 5B, 5A, 5C and 4-trinn south as well. For the classroom 4-trinn oriented west, during the registration day (wintertime), the curtains were already closed almost all day. Therefore, because of the configuration of this classroom, it is most likely that the curtains would be more often closed during spring and summer.

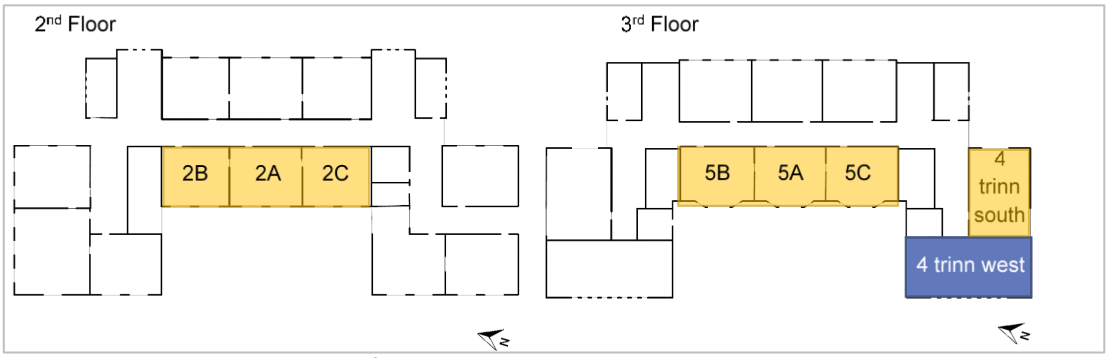


Figure 4.62: Use of lighting systems according to the classroom location

4.4.4 Conclusion

It appears that the daylight conditions in the classroom create three zones as seen in figure 4.63: near the windows, middle of the classroom and further away from the windows. If the lighting system were allowing to control these three zones independently it would lead to a better visual comfort and allow reduction of energy consumption. A complementary proposition would be to modify the current luminaires configuration of two rows of luminaires, figure 4.64, to create three rows to illuminate each zone independently.

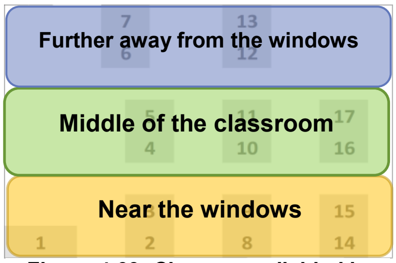


Figure 4.63: Classroom divided in three zones

Figure 4.64: Current luminaires configuration

Moreover, energy could be saved during spring and summer. Indeed, only electrical lighting for the zone further away from the windows would be used and therefore, during these periods, the energy consumption for lighting could be reduced to one third.

There is also potential for energy saving by changing the light sources from fluorescent to LED luminaires and by installing a light control system.

4.5 Registration in university building

4.5.1 Introduction

A refurbished university building of Sopot University of Technology (SSW) in Sopot, Poland (54,42N, 18,56E) has been studied. The building has a simple rectangular shape. The classrooms are located on all sides of the building surrounding a lecture hall in the middle, figure 4.65. The study was carried out 21st September 2020 from 9:30 to 14:30 local time. On the registration day the weather was sunny, the sky was clear without clouds. The registration was done in four rooms located on the 1st floor of the building with four orientations to cardinal directions, as shown in figure 4.65. The Room 1 is a computer laboratory and rooms 2-4 are regular classrooms.

All the studied rooms have windows with access to daylight and curtains that can be manually adjusted by users. The window openings towards the corridor do not influence lighting conditions in the classrooms as the corridor is not daylit and the luminaries there produce low levels of electric light (100 – 200 lux on the floor).

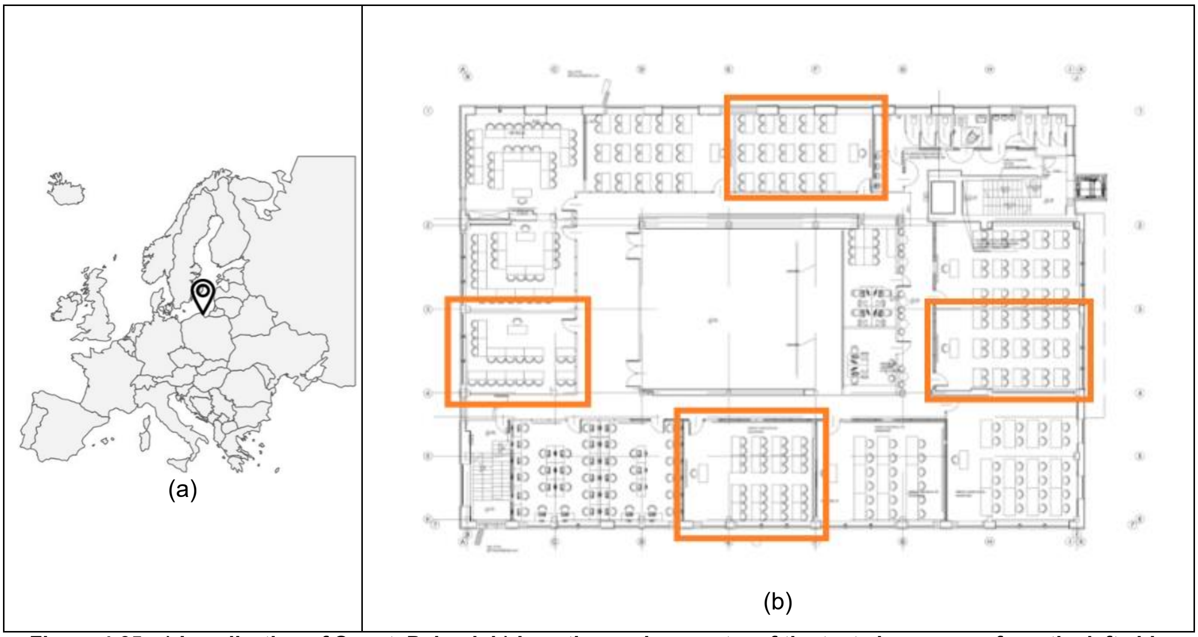


Figure.4.65. a) Localization of Sopot, Poland; b) Location and geometry of the test classrooms, from the left side (clockwise): 101, 105, 110, 113.

The electrical lighting in room 1, 3 and 4 consists of standard luminaires PXF Lighting PX1020301 QUAZAR 4X14W distributed evenly in the room. The room 2 was equipped with PXF Pisa 2x36W light sources.

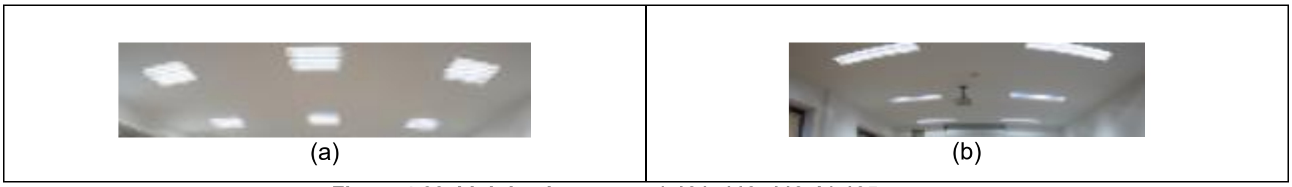


Figure 4.66. Lighting in rooms: a) 101, 110, 113, b) 105.

4.5.2 Methodology

The registration procedure was a little simpler than for the office and the school building. The measurements of the illuminance on the outside on the facade were collected every hour during the occupation time (09:30 - 14:30). The measurement points were carefully selected and are located in places that are not shaded by trees or buildings.

The participants (teachers and students) filled in the Lighting Diary forms during this time. The illuminance levels on the desks were also recorded.

4.5.3 Results

4.5.3.1 Lighting Diary registration

The data extracted from the diary forms is shown in figure 4.67.

In the room no. 1, figure 4.67, daylighting was the only light source used during the whole registration time, in the rooms 2 and 3 electrical light was used after the middle of the day, which cannot be explained by the low daylight level outdoors. In the north-oriented room (2) the use of electrical light may be caused by a need for a wormer light (lower CCT) than the blue light from the northern hemisphere. The east-oriented room has a huge depth, which limits the daylight penetration, the need for more light appears on the areas located in the longer distance from the facade (more than 5m).

The sun shading was used only in the room 4 from 12:30, which can be explained by the south-orientation of this room.

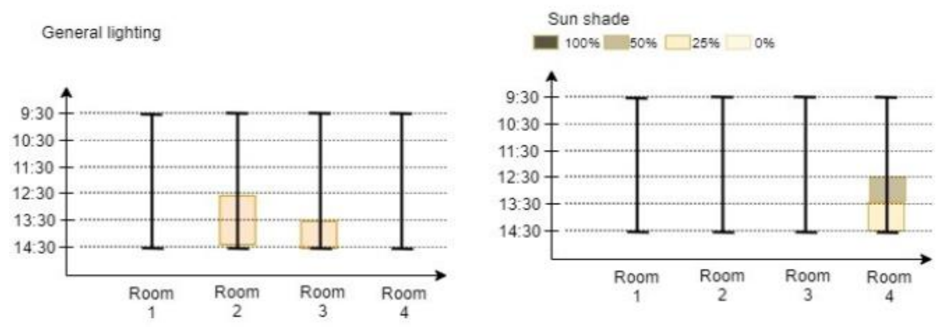


Figure 4.67. General lighting and sun shade, extracted from Lighting Diary.

4.5.3.2 Measurements

4.5.3.2.1 Facade illuminance

The registered daylight level outdoors oscillated between 16000 and 22000 lux (lower values on the north façade and highest on the south one), which gives a good potential for daylight use in interiors, table 4.6.

Table.4.6. Illuminance values [lx] for each measurement location. The maximum, minimum and mean level of illuminance on the façade for each measurement location.

Time	Façade 1 Room 101	Façade 2 Room 105	Façade 3 Room 110	Façade 4 Room 113
09:30	17030	16530	19620	19220
10:30	17970	16970	19060	19580
11:30	19420	18420	18640	19810
12:30	20430	17930	20840	20310
13:30	19730	19450	21540	21570
14:30	18750	18500	20400	19540
Max (lx)	20430	19450	21540	21570
Min (lx)	17030	16530	18640	19220
Mean (lx)	18888	17966	20016	20005

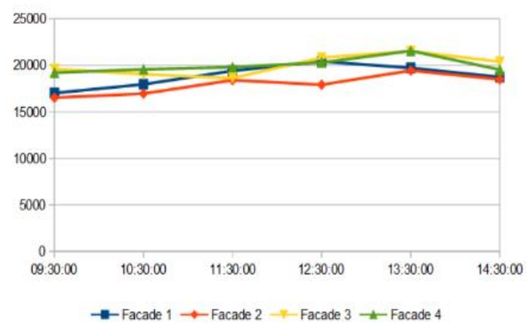


Figure.5. Il5uminance values on the façade on registration day.

4.5.3.2.2 Workplace's illuminance

The illuminances on the workplaces located near the windo, at the middle of the room and in the back of the room in the respective classrooms were also recorded to evaluate lighting conditions in each measurement point, figure 4.68.

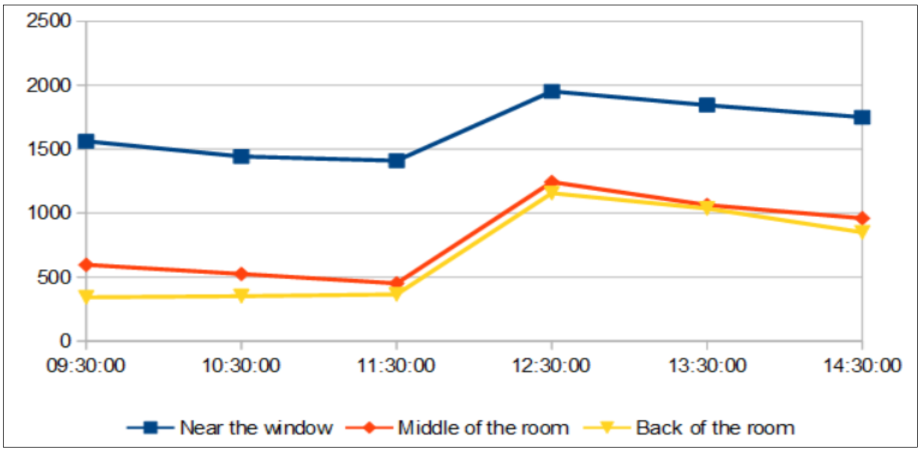


Figure.4.68. Illuminance values on workplaces on registration day, room 4.

4.5.3.2.3 4.5.3.2.3. Fish-eye images

Fish-eye images of the rooms were taken to assess the visual condition in the rooms from both the teacher's and the students' point of view, table 4.7. Analysis of the photographs as well as on-site observations, points toward the following conclusions. In the rooms 1 and 3, the teacher's location in the classroom makes that her/his view direction is toward the windows. It means that she/he is exposed to a bright light from the window located at the middle of her/his visual field. In addition, the outdoor surrounding visible by the window is very bright (white building), which may lead to possible reflections and high level of the brightness of the elements of the view outside the window. Such a location of the teacher's workstation in relation to windows may cause glare and potential specular reflections. This may cause the situation where the shading curtains are used more often, which will lead to more frequent use of the electric light. Students in rooms 1 and 3 have no possibility for view out without turning the body and the head by 180 degrees, which is unfortunate, as shift to the distance focus is positive for the eye's health and for the relaxation of the mind.

Table.4.7. Fish-eye photographs for rooms.

	Daylight	Daylight+Electrical light	Electrical light+blinds
		Room 101	
Teacher view position			
Students view position			
		Room 105	

Teacher view position			
Students view position			
Room 110			
Teacher view position			
Students view position			
Room 113			
Teacher view position			
Students view position			

4.5.3.2.4 Simulations

To find out how are the general daylighting conditions in this building, computer simulation have been carried out. The results show that the average daylight factor is lower than 2% in all rooms, the rooms 101 and 113 have only 1,2% and 1,3% average daylight factor, respectively, and daylight autonomy lower than 30%. In the light of this finding, extensive use of electric light is expected for the most part of the daytime during the year.

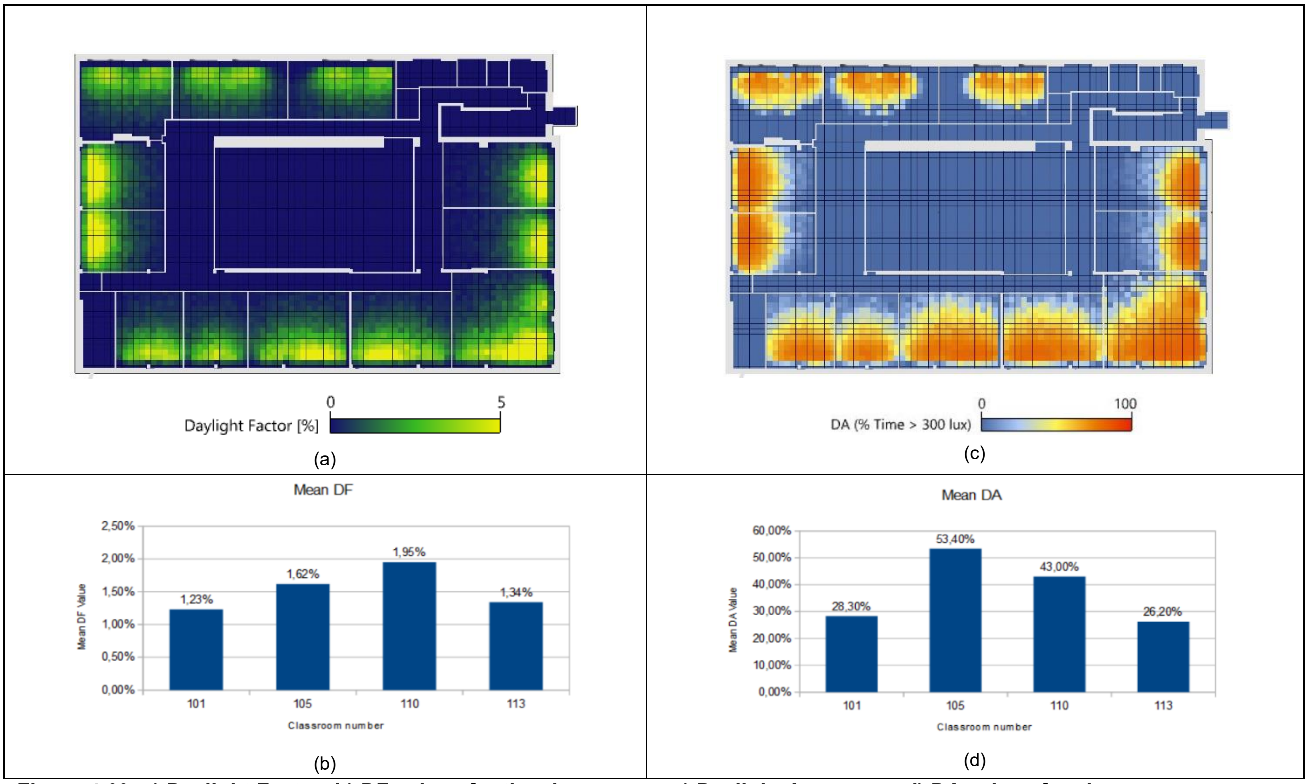


Figure 4.69. a) Daylight Factor; b) DF values for the classrooms; c) Daylight Autonomy; d) DA values for classrooms.

4.6 Registration in Industry building

4.6.1 Introduction

The industry building chosen for the registration was Elmarco lighting factory in Gdynia, Poland (54°,45′ N; 18° 45′ E), figure 4.70. The building consists of two parts: the main building and the factory building. The main building includes lobby, the exposition, offices and the auxiliary rooms. In the factory part there are 7 different workrooms (assembly room, ironworks room, decking room, polishing room, painting room, carpentry room, welding room) and the warehouse. Some of the workshops are illuminated by skylights.

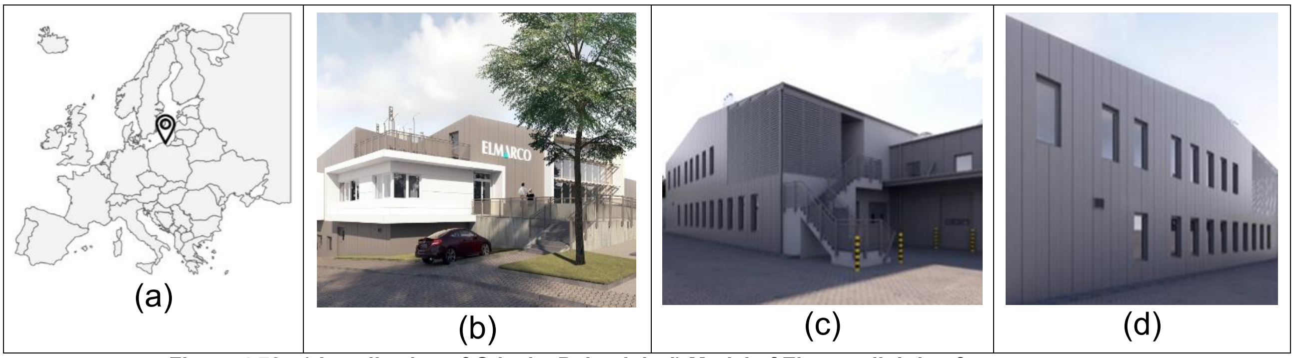


Figure.4.70. a) Localization of Gdynia, Poland; b-d) Model of Elamrco lighting factory.

4.6.2 Methodology

The procedure consisted on measurements on the side (outside facade and workplaces illuminance), Lighting Diary occupancy registration and photographic documentation (traditional and fisheye photographs).

To start with, there was conducted preliminary study on 5 working days (between 10.02-14.02) to recognize the general lighting conditions on the facade and indoors.

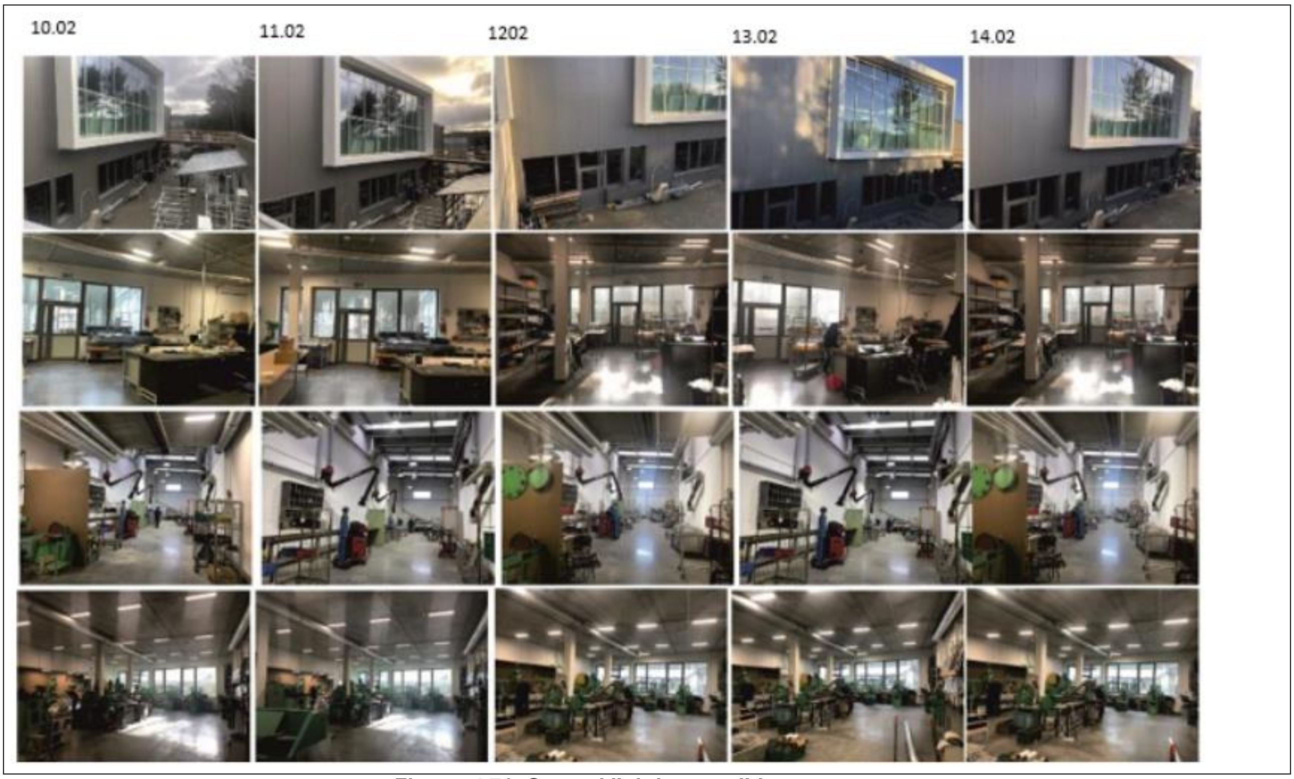


Figure. 4.71. General lighting conditions.

Afterwards, the more detailed study was carried out in one working day – 21 September 2020 from 9:00 to 15:00 local time. Participants of the study was the staff working in 8 rooms in the factory.

At that time all participants filled in the Lighting Diary forms. At the same time, measurements of the levels of illuminance on the outside facade were collected every hour. The illuminance levels on the desks were also recorded.

The location of the study was in the workrooms with different functions: assembly room, ironworks room, decking room, polishing room, painting room, carpentry room, welding room and warehouse, figure 4.72.

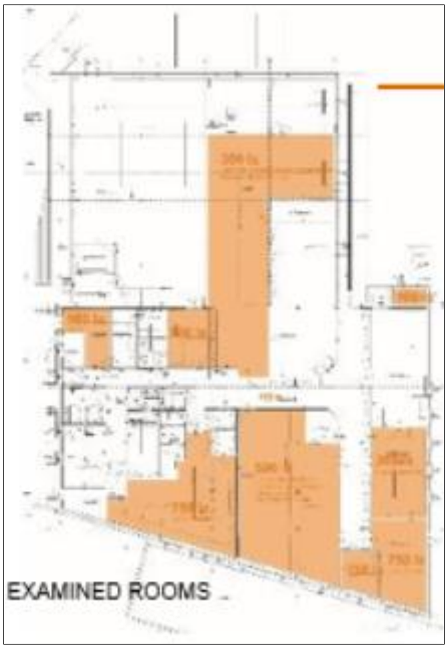


Figure 4.72 Examined rooms

The rooms were selected with different orientations: south-eastern and north-eastern. The geometries and arrangement of the room's furniture are typical for this building and are shown in figure 4.73. The rooms are presented in the order of the work steps. The rooms 1-5 have windows with access to daylight. In the room 4 there are curtains that can be adjusted by the participants. The rooms 6-8 have roof windows.

The walls are painted with white paint, the floor is covered with matt wooden tiles. The rooms are equipped with the furniture covered with paint in different colours (depending on the device). The reflectance of the room surfaces was white paint (0.70), ceiling white paint (0.70), furniture metal painted (0.55), outside ground – paving stone + asphalt (0.20).

Figure 4.73. Views of the indoor working spaces.

The electrical lighting in the rooms consists of luminaires, which are shown in figure 4.74. All the luminaries are evenly distributed in the rooms.

Figure 4.74. Lighting in rooms a) 1-6 and 8; b) Lighting in room 7.

4.6.3 Results

4.6.3.1 Diary

It appears clearly that all occupants use electrical light all day, independently on the daylight outdoors and/or possible breaks during the day. The sun shading system, consisting of white, manually adjustable blinds was not used at all in all the rooms, either.

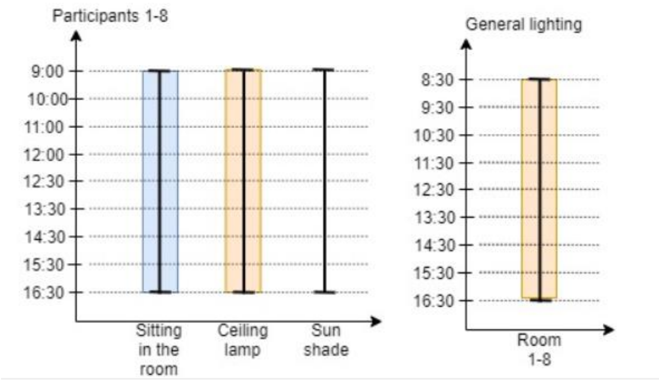


Figure 4.75. Data extracted from Lighting Diary.

4.6.3.2 Measurements

During the registration day, the outdoor illuminance levels measurements were collected hourly in the same eight positions on the façade – in front of the window in the middle of each room. The measurement points were carefully selected and are located in places that are not shaded by trees, buildings and are easily accessible.

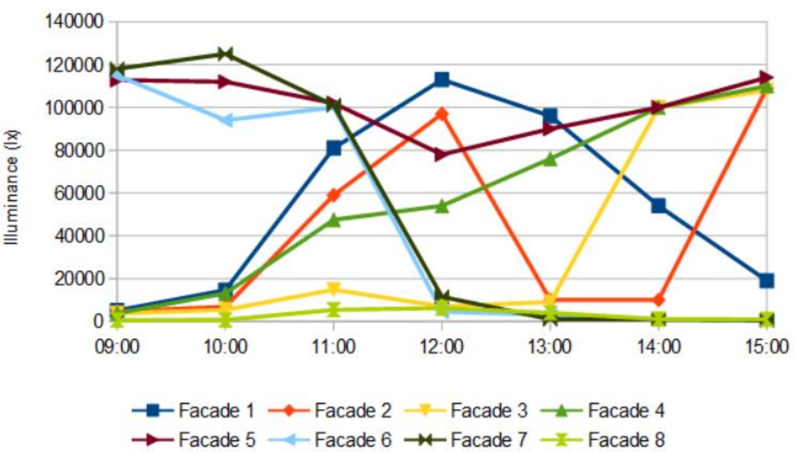


Figure 4.76. Illuminance values on façade in registration day.

The lighting conditions are strictly connected with electric lighting, not only in the rooms with skylights but also with standard windows. According to the Lighting Diary results, all the workers who participated in the study reported the use the electric lighting throughout the whole workday, regardless of daylight conditions. This may be due to several reasons. The factory operates on the principle of handcrafted production, based on precise manual work, which requires stable and good lighting. In addition, the geometry of the rooms –due to the size of the machinery - differs and some rooms are purely daylighted.

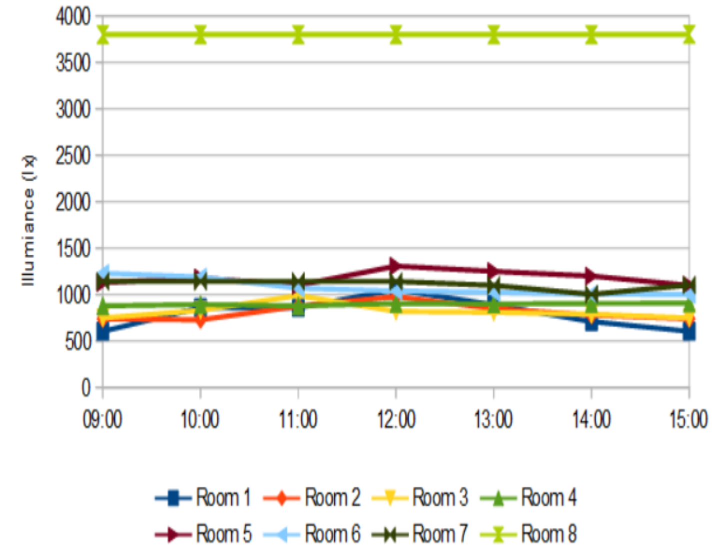


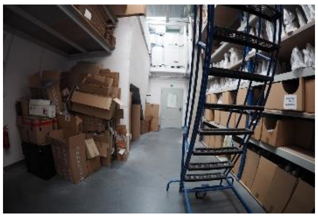
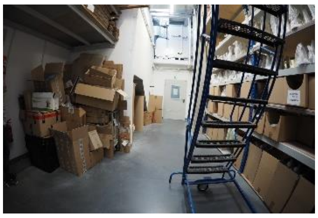
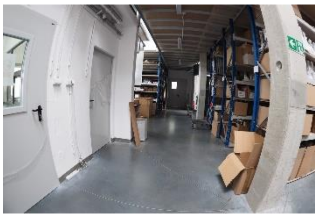
Figure 4.77. Illuminance values on workplaces in registration day.

As most of the rooms with standard windows have a north or north-eastern orientation, a risk of solar glare is low. Still, the floor reflectance is hight and slightly glossy. In the morning, reflections from the standard windows appear on floors in rooms 1-5, which could be examined more. The illuminance from electrical light is uniform in all workshops, a better adjustment of the position of the lamps and the direction of the light in relation to visual tasks could increase visual clarity.

Table.4.6. Fish-eye photographs for rooms.

Room 1		Room 2	
Daylight	Daylight+Electrical light	Daylight	Daylight+Electrical light
			
			
Room 3		Room 4	
Daylight	Daylight+Electrical light	Daylight	Daylight+Electrical light

			
			
Room 5		Room 6	
Daylight	Daylight+Electrical light	Daylight	Daylight+Electrical light
			
			
Room 7		Room 8	
Daylight	Daylight+Electrical light	Daylight	Daylight+Electrical light
			
			
Room 9		-	
Daylight	Daylight+Electrical light	-	

		-
		-
		

5 Conclusions

The report starts with the introduction, chapter 1, where the main objective of the work is formulated, namely, to examine how the public buildings are used regarding lighting; both daylight and electric light is considered.

In the chapter 2 a review of codes and requirements has been done. It starts with a discussion about general aspects of codes (subchapter 2.1) and presentation of international standards CEN and ISO (2.2) and follows with description of CIE reports and other internationally recognized guidance books (2.3). Then national recommendations are presented (2.4). Finally, the impact of codes on architectural design is elaborated based on the interviews with architectural offices (2.5).

Chapter 3 presents the studies of buildings usage based on the extensive literature review. The following public building types are included: offices, schools, university buildings, hospitals, commercial buildings, industry buildings and libraries.

Chapter 4 focuses on occupancy and use of lighting systems. It starts with a discussion of the occupancy simulations and their usefulness in the current project context. Then, it follows with occupancy registration and use of lighting in chosen buildings located in different European countries. It includes registration in an office building in Italy, a primary school building in Norway, a university building in Poland and one industry building, also in Poland. The research method used in registration consisted of simultaneous registration of occupancy and use of (day)lighting with the help of a self-report diary, and light-technical measurements. The diary registration and the measurements were performed at the same day, in most cases in February/March 2020, that is just before the pandemic lock-down in Europe. Then, the use of electrical light had been compared with the occupancy and (day)light level indoors/outdoors. The registration was carried out in each of the buildings for one day only. As such, it should be considered a form of stick sample to check the findings from the literature study presented in the chapter 3. Computer simulations were done for school and university buildings to estimate the light level during the whole year.

In the present chapter, the main findings are summarized.

The criteria of what stands for good lighting and what kind of metrics to adopt are partly depicted by standards, codes and national building recommendations, and mandatory regulations influence the way the architecture is created. There is a lack of coherence between diverse metrics and lighting appraisal methods, as well as a growing number of various criteria and ideas how to handle variety of electric lighting and daylight. National building codes (for daylight) normally refer to most crucial aspect of daylight parametrization and evaluation, through criteria like windows dimension and orientation, obstructions and so on. Following lighting codes and recommendations will not ensure good quality of design, but it usually help to prevent poor decisions, both in lighting and daylighting. The recommendations should be formulated clearly, the measures should be few but applicable to most situations, they should be easy to understand and simple to use, but it is often not a case.

The analysis of three case studies in different countries demonstrated that the main factors influencing design decisions were i) design idea / objectives to follow user/investor visual and comfort needs, ii) building regulations for a given country and iii) daylighting recommendations found in national building or lighting regulations. In addition to mandatory national codes, also the non-mandatory, LEED or BREEM codes are being used.

Occupancy has a substantial impact on building use and performance, according to the International Energy Agency–Energy in Buildings and Communities [IEA, 2021]. It considers occupancy patterns and user behaviour as one of the main parameters affecting the overall building performance, see the Report A.1. The occupancy patterns and user behaviour are generally defined as the occupants' behaviour towards building energy-related operations during the working hours. Although numerous studies have been carried out in the area, there are still many challenges and opportunities in addressing the influences of occupant behaviours in buildings.

The effects of occupant behaviours can be classified into three main categories, the occupancy, interactions, and behavioural efficiency. The occupant's data mainly come from occupancy and interactions, such as occupant's presence, occupant's number, occupancy, and behavioural interactions with building service systems, and others. Besides, behavioural efficiency, which means enhancing of occupant energy awareness and corresponding behavioural changes, is crucial to building energy consumption. It emphasizes the willingness of occupants to change or correct the inappropriate energy behaviour based on various educational approaches.

Within the scope of this report, the registration occupancy process regarding user's changes in activity or movements vs. related manually operation of (day)light/projector/curtain may be considered as a supporting tool for a preliminary analysis of energy saving measures before the adoption of a lighting control systems. As it appears in the conducted study, user behaviour influences use of lighting systems much more than the required thresholds of lighting values.

The registration confirms a pattern of occupants' behaviour found in literature. In general, occupants consider the visual environment at the workplace when they enter or leave the room. It happens mainly at the beginning (adjustment of blinds and switching on the electric light) and at the end of the working day (switching of the light).

Among the studied buildings, the industry workshops are places where electric light is switched on from when the first worker enters the building to when the last worker leaves the building. In buildings where users move in-out into the room many times during the day (primary school building and partly university building) the adjustment happens more frequently. Another decisive factor in those building types is the use of a projector for teaching purposes, which generates the need for very low general light level in the room. Covering the windows and switching off the electric light happens accordingly, but the pattern is not consistent.

In general, the changes in the electric lighting use follow the occupancy pattern, not the light levels but, considering the different daylight availability on the desks, a potential energy saving, compared to the current electric light usage, could be achieved by using a control system able to adjust the electric light contribution to the specific need for each user's position.

In the buildings considered, it appears that the daylight conditions create different zones as a function of the users' position concerning the window: near the windows, middle of the room and further away from the windows. Moreover, the placement of light sources for general lighting is always on the ceiling and with homogeneous distribution. There are no systems to regulate the luminous flux, and the control is on/off. If the lighting system allows controlling lighting zones independently, it will lead to a better visual comfort and energy saving.

The literature review also demonstrates:

- The occupancy profile is one of the driving factors behind discrepancies between buildings' measured and simulated energy consumption.
- The blind occlusion level and frequency of adjustment of window blinds can affect the daylight condition and energy consumption.
- Daylight harvesting systems can perform well, but they need careful design and commissioning.
- The occupants prefer to have control over the lighting. Thus some types of manual controls should always be provided. Automatic controls are generally disliked.
- In commercial buildings, light is also used as one of the aesthetical elements that can act as visual cues in the design of memorable experiences, a brighter environment is used as a stimulus, especially in the marketing approach, following the idea that the brightly lit environments are more arousing than dimly lit ones. Also, luminance contrast is used to influence the consumers' behaviour, as the human visual system reacts better to changes and spatial variation in the visual field, the colour of light is chosen according to the type of retail and emotions the shop would like to create in users, in this context tangible cultural differences have been found.
- Occupant behaviour agent-based modelling is challenging as the behaviour of an occupant is influenced by other shoppers and by employees.
- Daylight was the primary source of lighting, but electrical lighting cost, convenience, and performance were investigated extensively in commercial buildings. However, some occupants, researchers and lighting practitioners believe that daylighting may provide benefits like increased occupants health and well-being, which could increase productivity or sales.
- In commercial buildings, highly glazed spaces are attractive in many ways by providing daylight, solar heating, aesthetics. However, their thermal behaviour remains challenging to predict.

- Occupancy controls have the most significant potential in spaces where occupancy varies throughout the day, and daylighting controls should only be applied in portions of the floor area where sufficient daylight exists.
- Individual control strategies save on average between one-quarter and one-third of lighting energy, and multiple control strategies can capture up to nearly 40 per cent savings on average.
- The effects of the physical environment on the healing process and well-being have been proved to be increasingly relevant for patients and their families (PF) and healthcare staff.
- Evidence has indicated that appropriate environmental lighting with characteristics similar to natural light can improve mood, alertness, and performance.
- The restorative effects of windows and views have also been documented.