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A study about daylighting knowledge and education in Europe. Results from the first phase of the DAYKE project

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Abstract

This paper presents selected results from the first stage of DAYKE (Daylight Knowledge in Europe), a 3-phase project that investigates the knowledge on daylighting in buildings among both architecture students and practitioners across Europe. The data presented are based on subjective judgments from 561 students from 8 architecture universities and schools in the EU, collected through two surveys in 2018.

The key findings were: (i) variations in the spatial distribution of comfort and mood in the classrooms were observed depending on sky conditions and distance from windows; (ii) the average daylight factor DF_m showed a good agreement with subjective judgments on the amount of daylight in a space: daylit spaces with highest DF_m values were rated with the best scores; (iii) experts and non-experts provided similar judgments on the perception of a daylit environment; (iv) a general lack of knowledge about daylighting metrics, regulations, assessment tools and software was highlighted; furthermore a difficulty in implementing daylighting into the design practice was also identified.

Keywords: *DAYKE; Survey among students; Daylighting knowledge; Perception of daylit spaces; Education in Europe.*

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1. Background

Daylight is widely considered a strategic resource towards the design of a human-centred and energy efficient built environment. Linked to both visual performance and comfort, daylight fosters attentiveness, interaction and communication. It stimulates mood and well-being via image forming and non-image forming processes. Moreover, given its impact on the human circadian rhythm, is it also regarded as an important resource for the creation of healthy indoor environments (van Bommel 2006; Veitch and Galasi 2012; Andersen et al. 2012, Bellia and Bisegna 2013; Amundadottir et al. 2017). Often considered as a design driver (Lam 1986; Lo Verso et al. 2014), daylighting can also lead to optimal solutions regarding form, function and usage of technology in buildings (Mardaljevic and James 2013; Costanzo et al. 2017). Therefore, the European Union (EU) invests many resources in the dissemination of new energy saving strategies and policies (European Commission 2010, 2011) and electric lighting design issues have been addressed in several architectural studies and framework programs. In lighting, new circadian and climate-based daylight metrics and assessment methods are widely discusses, yet there is no consensus on what the optimal criteria are. Nevertheless, new trends can be highlighted, as shown by the daylight evaluation methods specified in the European Standard EN 15193-1 (CEN 2017) and in the new European Standard '*Daylight of Buildings*' (Deroisy 2017; Mardaljevic and Christoffersen 2017; CEN 2018), which are expected to greatly influence the design of buildings. Architects of today and tomorrow have a great responsibility in the construction of increasingly energy-efficient buildings. It is therefore important that they understand daylighting metrics and regulations, as well as their implications on the design process.

However, recent studies have revealed that there is an inadequate knowledge about lighting retrofitting and energy performance evaluation of modern lighting systems

(Dubois et al. 2015; IEA 2016). Other studies indicate that the use of the latest daylighting evaluation tools and metrics remains limited, with practitioners tending to rely on experience, simplified methods and rules of thumb in the early design stages (Reinhart and Fitz 2006; Galasiu and Reinhart 2008; Reinhart and Lo Verso 2010; IEA 2016; Tregenza and Mardaljevic, 2018). As a result, an optimized daylighting is often lacking in the building design practice.

Within this context, the DAYKE (DAYlighting Knowledge in Europe) research project was set with the goal of describing potential daylight education deficiencies in architectural education, training and practice in the EU among architecture students, practitioners and researchers. Another goal was to explore how daylighting experts and non-experts as well as building practitioners and professionals perceive and describe a daylit space.

2. The DAYKE project

The framework of DAYKE consists of three primary and three secondary areas of investigation (Figure 1). The primary areas concern: (i) *perception* of a daylit space; (ii) *knowledge* about daylighting standards and regulations; (iii) *educational offer* related to daylighting design for university students in the building sector. The secondary areas focus on aspects that may vary in the different participating countries: (iv) *preferences*; (v) *professional training*; (vi) *cultural aspects.*

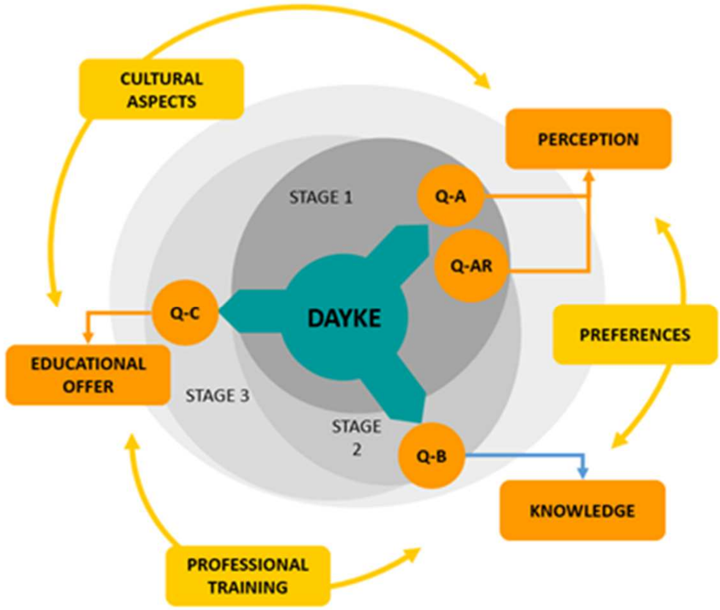

Figure 1. The DAYKE project framework: 3 stages with 3 different questionnaires (Q-A and Q-AR; Q-B; Q-C).

The three main areas of investigation correspond to three project stages. For each stage, different analysis tools and target samples were set, as follows:

- Stage 1 focus on daylight perception among students of European universities and schools of architecture. The tools are Questionnaires A (Q-A) and AR (Q-AR).
- Stage 2 investigates knowledge of daylighting design metrics and regulations among practitioners and researchers. The tool is Questionnaire B (Q-B).
- Stage 3 reviews educational offers and is addressed to researchers and university teachers. The tool is Questionnaire C (Q-C).

The whole DAYKE toolkit consists of *ad hoc* questionnaires developed by the authors with the aim of providing extensive information on the above investigation areas. For the preparation of such tools, several surveys reported in the literature were used as references, especially for the '*perception*' part, that is how the respondents perceive daylighting within a given space (Eklund and Boyce 1996; Veitch et al. 2005; Winterbottom and Wilkins 2009; Fornara et al. 2006; De Giuli at al. 2012; Lo Verso et al. 2014, 2016; Ricciardi and Buratti 2018; Chen et al. 2019). Furthermore, other studies were consulted to understand potential connections between the architectural features of a space and its perception by occupants (Heschong Mahone Group 1999, 2003a,b; Reinhart and Weissman 2012).

3. DAYKE stage 1: daylighting knowledge and perception by architecture students

Stage one of DAYKE consisted of two different surveys that were carried out in 2017 and 2018, with around 880 participants involved in total.

The first survey (2017) used questionnaire Q-A and was conceived as a pilot study. Over 250 subjects from architecture schools in five countries (Germany, Italy, The Netherlands, Poland and Spain) participated in that phase. The method and the main results were the object of a dedicated publication (Giuliani et al. 2017).

The second survey (2018) used questionnaire Q-AR and was conducted in two sessions, in May-June 2018 (hereby referred to as 'Late Spring Session' LSS) and in November-December 2018 ('Late Fall Session', LFS). The overall sample includes 623 respondents from six countries (France, Germany, Italy, The Netherlands, Poland, Switzerland).

Some preliminary results of LSS were presented in the PLEA 2018 International Conference (Giuliani et al. 2018). The present paper expands on the previous work including LFS and adding more in-depth analyses.

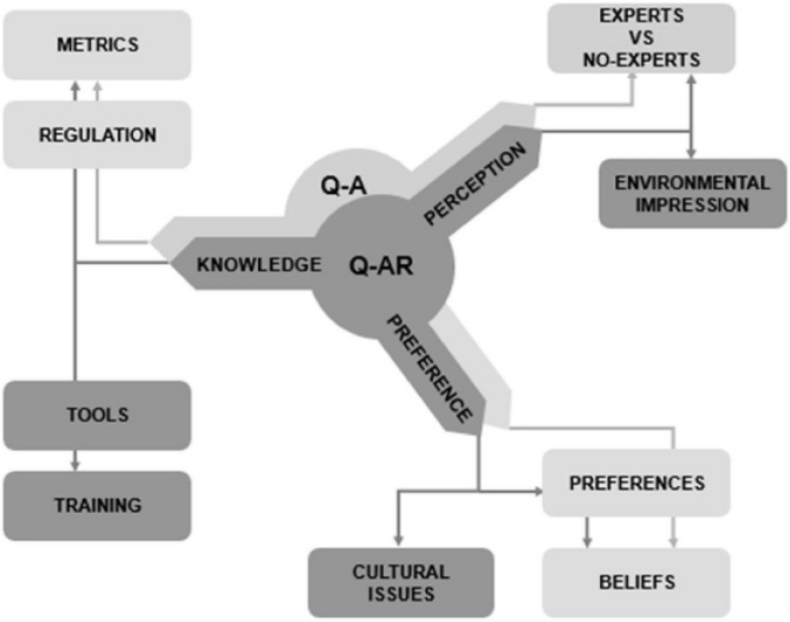

Figure 2. Areas of investigation of Q-A (light grey) and of the expanded Q-AR (dark grey).

3.1. Questionnaire Q-AR

The Q-AR structure is based on a revised and upgraded version of the questionnaire Q-A (*perception*, *preference* and *knowledge*), with the introduction of new sections and questions that were considered fundamental after the analysis of the results of Q-A (Figure 2). Q-AR therefore consists of five sections: (1) *environmental impressions*; (2) *perception*; (3) *preferences*; (4) *knowledge* and (5) *socio-demographic personal information*. Figure 3 synthesizes the type of questions that were used in each section. These were studied to obtain specific information and the type of answers was constructed accordingly, using different types of scales (unipolar and bipolar). The '*perception*' part (sections 1 and 2) was administered simultaneously to experts and students (non-experts), while the rest was administered to students only.

SECTION	TOPIC QUESTION	ANSWER TYPE
1 **ENVIRONMENTAL IMPRESSION**	- Weather - Comfort - Sitting position (ref. Windows) - Sitting position (ref. Blackboard) - Visible sky portion - Subject's mood	- Snowing/Very rainy/Cloudy/Partly.cloudy/Sunny - Very unpl./Unpleasant/Neutral/Pleasant/Very Pleas. - Very far/Far/Neither Far N. Close/Close/Very close - Very far/Far/Neither Far N. Close/Close/Very close - No sky at all/A small portion/A large portion - Very negative /Negative/Neutral/Positive/Very positive
2 **PERCEPTION**	- Overall Daylit Environment - Windows and View Out - Colour Perception - Maintenance/System Control - Qualitative Aspects - Comfort Conditions (r. Visual tasks) - Daylight Appearance and Glare	- Too Low /Low/Acceptable/ High/ Too High - Absent/Very Low/Low/High/Very High - Very Poor/Poor/Acceptable/Good/Very Good - Very Poor/Poor/Acceptable/Good/Very Good - Very Poor/Poor/Acceptable/Good/Very Good - Very Poor/Poor/Acceptable/Good/Very Good - Too Low /Low/Acceptable/ High/ Too High
3 **PREFERENCES**	- Type of lighting and daylighting - Daylighting design examples - Usefulness of daylighting design - Limits and implementation	Multiple-answer questions
4 **KNOWLEDGE**	- Daylighting metrics/indicators - Daylighting software - Regulations (EU/ National /Local)	Yes/No and open answer questions
5 **PERSONAL INFORMATION**	- Gender / Age / Nationality - University / Degree / Field of study - Previous training in daylighting design or analysis (curricular / extra-curricular)	Multiple-answer and open questions

Figure 3. Questionnaire Q-AR: synthesis of the tool with questions and answer types.

The first section, '*environmental impression*', is a set of subjective data. It is based on multiple-choice questions and 5-point bipolar scales with semantic descriptors for each point. It aims at collecting subjective information about sky condition, spatial position with respect to windows and blackboard/whiteboard/smartboard as well as perceived mood and comfort. The choice of collecting subjective rather than objective information (such as distance in meters, illuminance values in the room and so on) is linked to the search for relationships between climate, spatial position and perceptual aspects. In other words, subjects who describe a certain sky condition and a certain distance from windows, also assess their mood and comfort level. In addition, the choice of working with subjective data is due to a need to simplify the data analysis procedure compared to the first survey (2017). To work on large quantities of responses (sample: n=880), it was necessary to find an agile method to combine environmental and perceptive data.

The second section, '*perception*', is based on 5-point unipolar and bipolar scales with semantic descriptors for each point. This part investigates aspects concerned with the quantity and quality of daylight in the space considered, in terms of daylight amount and uniformity, presence of dark zones, colour perception, daylight appearance and glare, overall visual comfort, pleasantness. The evaluation was based on a benchmark method that compares judgments of experts (lecturers, professors, assistant professors, PhD candidates) and non-experts (students). Such an approach was used in several other studies, for instance in (Fornara et al. 2006). For this evaluation, subjects were asked to assess daylighting within the classroom where they were attending a lecture using a five-point scale with specific labels at each point.

The third section, '*preferences*', is based on multiple-answer questions created to investigate preferences towards different types of (day)lighting conditions and daylighting use in buildings, beliefs and cultural issues. Besides, pictures of 20 iconic and representative buildings considering daylight and energy efficiency design are presented to respondents, who had to choose the best and the worst building example and explain the choices. The results of this part are not included in the present publication and will be addressed in a future dedicated paper.

The fourth section, '*knowledge*', is based on yes/no and open answer questions to investigate the knowledge on metrics, appraisal methods and standards (European, national and local).

The last section, '*personal information*', includes participants' socio-demographic (gender, age and so on) and daylighting education information including daylighting design training.

The full questionnaire Q-AR is available upon request.

3.2. Survey Q-AR: description of the method

The survey campaign was conducted in six countries (France, Germany, Italy, The Netherlands, Poland, Switzerland) within 8 higher education institution, namely:

1. CH: École polytechnique fédérale de Lausanne (EPLF)
2. DE: Technische Universität Berlin (TUB)
3. FR: Ecole Nationale Supérieure d'Architecture de Normandie (ENSA)
4. FR: Ecole Supérieure d'Architecture de De Saint-Etienne (ESASE)
5. IT: Politecnico di Torino (POLITO)
6. NL: Technische Universiteit Delft (TU Delft or TUD)
7. PL: Politechnika Gdańska (PG)
8. PL: Sopocka Szkoła Wyższa (SSW).

623 respondents (including 62 experts) were involved in 31 survey sessions, conducted in 2 different stages in 2018: May-June (LSS) and November-December (LFS). The surveys were carried out at different times during the day, generally in the morning (10-12 am). The questionnaire was submitted during a scheduled lecture, so respondents were familiar with the room and the daylight conditions in it. They were asked to remain seated when filling in the questionnaire. The visual task performed by respondents was reading and writing on their electronic device (smartphone, laptop, notebook), as well as reading the blackboard/whiteboard/smartboard (i.e. where the teacher displays the lecture).

For each classroom (Figure 4), environmental data and daylighting indicators were collected. In detail, the window-to-floor ratio (WFR) and the window-to-wall ratio (WWR) were computed, to describe the amplitude of window area. Furthermore, the mean Daylight Factor (DF_m) was analytically calculated using the Lynes formula (Lynes 1979). Such metric was used as a synthesis of geometric (room area, window area, magnitude of obstructions) and photometric (surface visible reflectance R_v and glazing visible transmittance T_v) properties of each room. The values that were found are summarized in Figure 5.

Figure 4. Overview of some of the classrooms used in the study.

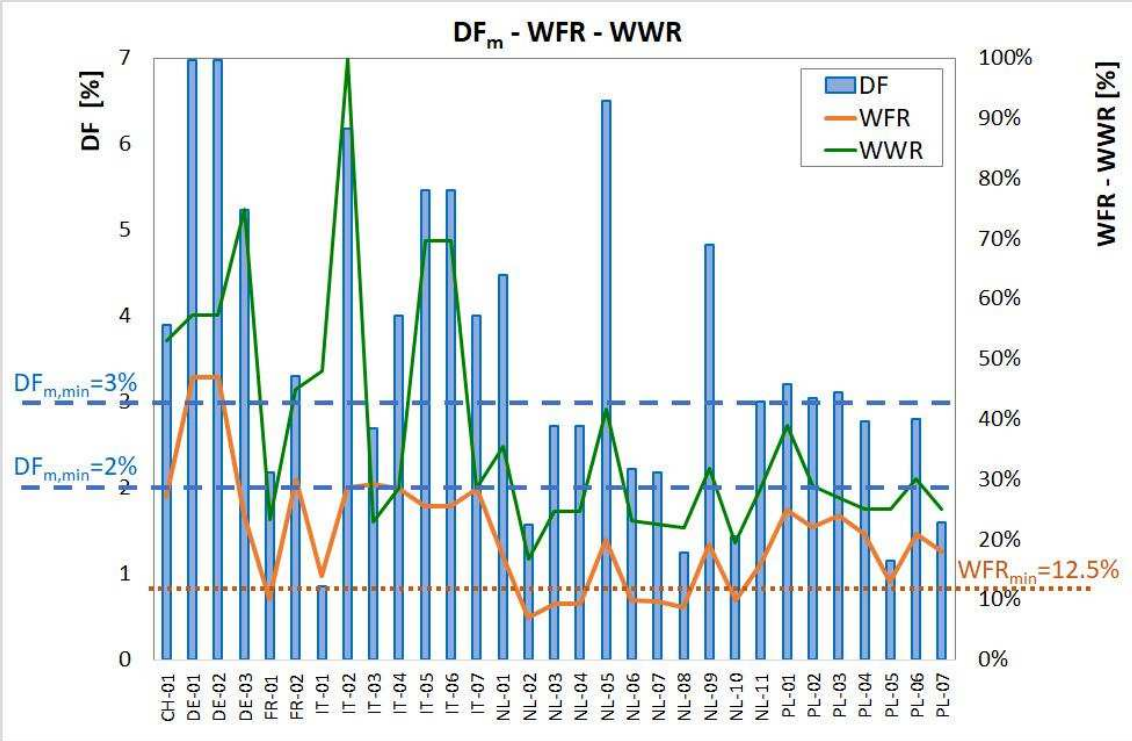

Figure 5. DF$_m$, WFR and WWR values for the 31 classrooms that were considered in the study.

A condition with DF$_m$ > 3% was observed in over half of the classrooms analysed (51.7% of cases), which is the most common standard requirement (for instance: UNI 2008), while a condition with DF$_m$ > 2% was observed in 76.9% of spaces (CIBSE 2011). Differently, 23 spaces out of 31 (74.2%) follow a geometric requirement based on the window-to-floor-ratio (WFR > 0.125), recommended in some countries like Italy (Italian Law Decree 1975) or Poland.

3.3. Q-AR: definition of new research goals

Following the results of the Q-A survey (Giuliani et al. 2017), new research questions (RQ) were defined:

- **RQ1**: Are comfort and mood affected by the perceived sky condition and by distance from windows?
- **RQ2**: Do experts and non-experts report similar perceptions of a daylit space, i.e. does expertise on daylighting influence the perception of a daylit space?

- **RQ3**: Is there a relationship between DF_m and the perceived quality and quantity of daylighting in a space?
- **RQ4**: Which kind of knowledge do students have about daylighting metrics and regulations? Does it vary between bachelor and master students?
- **RQ5**: Do sociodemographic variables such as respondents' age and gender influence the evaluation of daylight conditions?

3.4. Statistical data analysis

To answer the above RQs, both descriptive and bi/multivariate statistical analysis were performed, using SPSS software v24 and different techniques of data analysis:

- RQ1 and RQ5: a multivariate analysis of covariance (MANCOVA) was computed on comfort and mood ratings reported by the students with the perceived sky condition as a between subject factor and distance from windows as a covariate, also controlling for the sociodemographic variables (i.e. gender and age).

- RQ2: the non-parametric Mann-Whitney U test was used to compare experts' and students' perceptions of a daylit space. This test was chosen due to the uneven distribution of the participants within the two groups (students n=561, experts n=62), consistently with previous studies (Dondi et al. 2007).

- RQ3: a MANCOVA was performed to investigate the effects of DF_m on the perception of a daylit environment, while controlling for age and gender. Overall quantity of daylight, daylight through glazed area and suitability of the number of windows in the room were the dependent variables.

- RQ4: The relationship between knowledge of metrics and regulations and the enrolment year of students within their university curriculum was investigated through a series of chi squared tests.

4. Results from Q-AR survey

RQ1: Are comfort and mood affected by the perceived sky conditions and by distance from windows?

In this section, data from experts and non-experts were combined.

A - Descriptive analyses

Descriptive analyses were subdivided into four sub-analyses. Each section addresses a cross-analysis of different pairs of variables taken from the section *environmental impression* (Fig. 3).

RQ1a: Do occupants report a higher comfort in the presence of clear rather than overcast skies?

The sky conditions that were reported by respondents had the following frequencies: clear sky 41.1%; partly cloudy 26.2%; overcast 29.3%; raining 3.4%. Sky conditions from overcast to clear therefore showed a comparable distribution frequency.

An increase in the comfort was noted in the presence of clear skies. Figure 6 shows the results of comfort depending on sky conditions. The percentage of 'pleasant' and 'very pleasant' responses increases along with the percentage of sky conditions from partly cloudy to clear skies. Conversely, the higher percentage of 'very unpleasant' and 'unpleasant' votes is observed for rainy or overcast sky conditions.

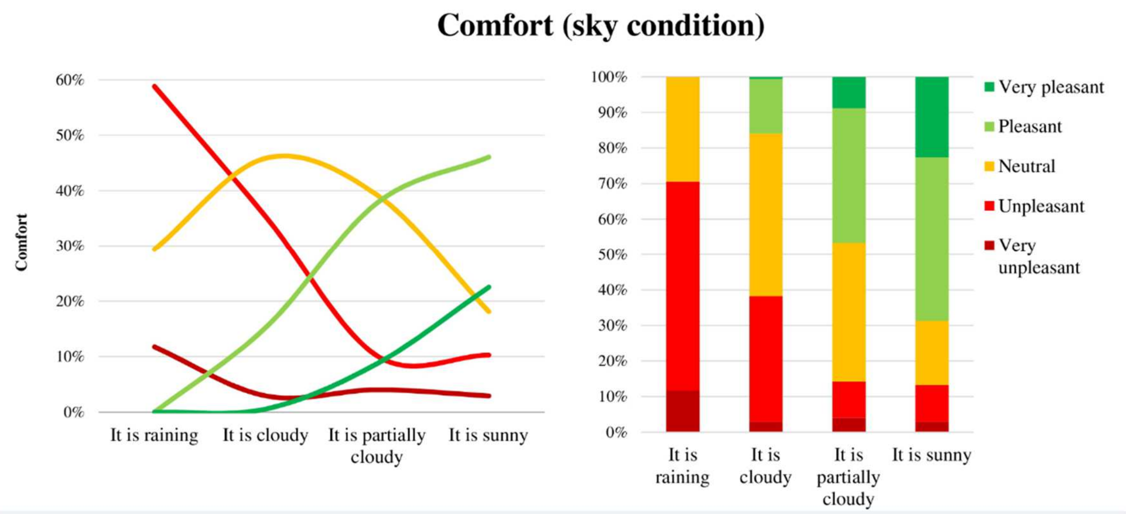

Figure 6. Distribution of *comfort* responses corresponding with the sky condition relieved by respondents. Absolute percentage of answers (left) and normalized data (right).

RQ1b: Do occupants report a better mood in the presence of clear rather than overcast skies?

Figure 7 shows the outcomes on mood depending on sky conditions. Most neutral moods occur under clear skies (Fig. 7a), while positive moods are uniformly distributed for the various skies, with peaks for partly cloudy and clear skies (Fig. 7b). If a relationship was observed between clear skies and higher scores on comfort (as shown in the previous subsection), the same does not seem to apply between clear skies and positive mood.

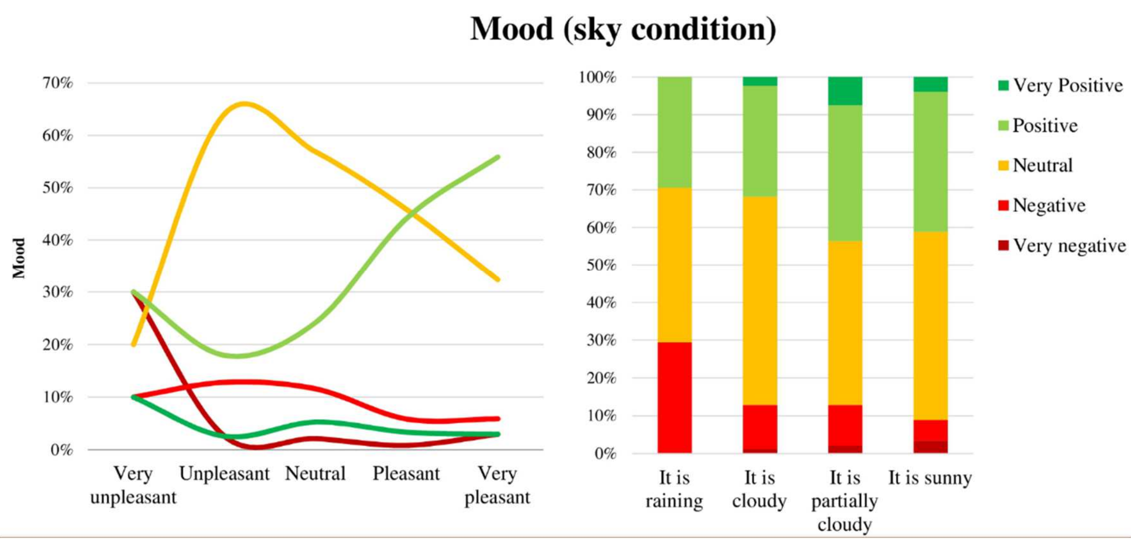

Figure 7. Distribution of *mood* responses corresponding with the sky condition described by respondents. Absolute percentage of answers (left) and normalized data (right).

RQ1c: Is there a direct and positive relationship between comfort/mood and distance from windows, i.e. do occupants report higher comfort and better mood for positions closer to windows?

The position with respect to windows was compared with the judgments on *comfort* (Figure 8) and *mood* (Figure 9). In general, there seems to be a direct relationship between position and both comfort and mood**.**

The *comfort* varies in relation to the distance from windows in the following ways:

- a higher percentage of comfort judgments (neutral to very pleasant) were reported by respondents sitting either in the central part of the room ('neither near, neither far from windows') or just 'close to windows' (but not 'very close to windows');
- more than 1/3 of students who were sitting far away from windows declared to be uncomfortable ('unpleasant comfort').

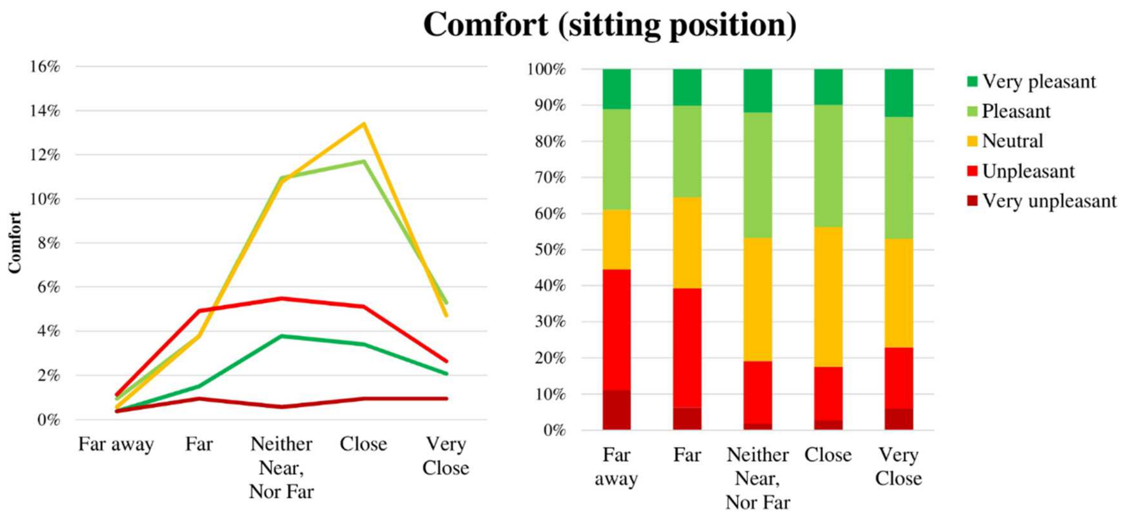

Figure 8. Distribution of *comfort* responses corresponding with the sitting position stated by respondents. Absolute percentage of answers (left) and normalized data (right).

The *mood* varies in relation to the windows position in the following ways:

- a higher percentage of negative moods were reported by respondents sitting far away from windows.

● the distribution of very positive moods is constant for all positions in the classroom while there is a greater presence of neutral or positive moods for positions closest to windows.

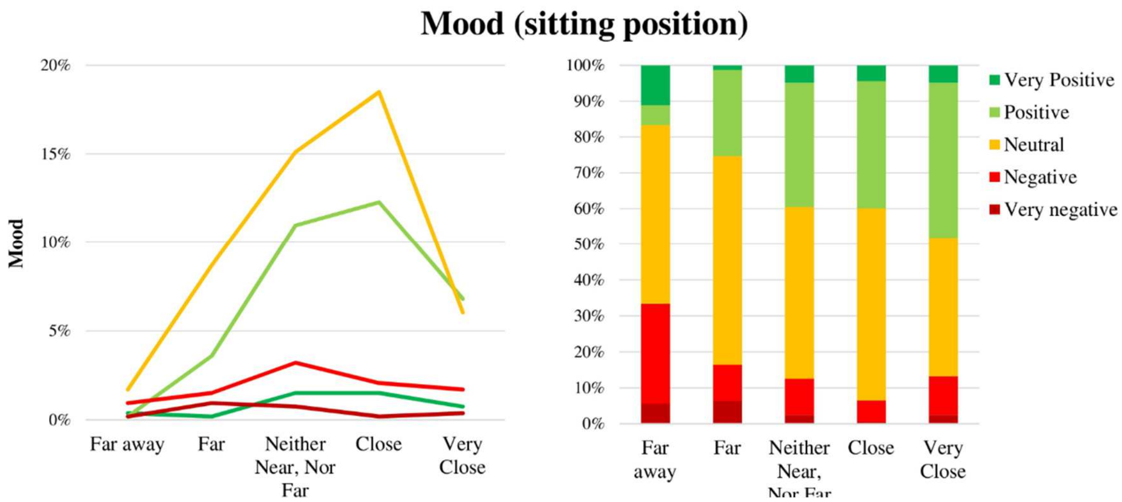

Figure 9. Distribution of *mood* responses corresponding with the position with regard to windows stated by respondents. Absolute percentage of answers (left) and normalized data (right).

B - Statistical analyses

The MANCOVA showed a main significant effect of the distance from windows (F(2, 477)=12.869, p=.000) and the perception of sky conditions (F(8, 956)=15.973, p=.000), on both comfort and mood: the closer students were to windows, the better they rated their comfort (visual and thermal) and their mood. Regarding sky conditions, rainy skies weres particularly associated with the lowest ratings on comfort and mood.

RQ2: do experts and non-experts report similar perceptions of a daylit space, i.e. does expertise on daylighting influence the perception of a daylit space?

In general, the evaluation of daylit space is convergent in both expert and non-expert population.

A - Descriptive analyses

For this analysis, significant questions of the '*perception*' section (Figures 3, 10) were aggregated into four macro-categories with a coherent content: (i) amount of daylight; (ii) quality of daylighting; (iii) quality of view out; and (iv) quality of windows.

AMOUNT OF DAYLIGHT
1. Quantity
2. Number of windows
3. Glazed area
4. Dark zones
5. Glazing cleanliness

QUALITY OF DAYLIGHTING
1. Pleasantness of the overall daylighting
2. Contribution of daylighting to create a stimulating environment
3. Concentration due to the overall daylighting
4. Overall comfort due to daylighting

VIEW OUT QUALITY
1. Obstruction outside
2. Distractions due to the view out
3. Pleasantness of the view out

QUALITY OF WINDOWS
1. Shading system daylight control
2. Shading system maintenance
3. Glazing cleanliness

Figure 10 The four macro-categories concerning key aspects of daylighting.

Figure 11 illustrates expert vs. non-expert responses to the macro-categories listed above. Judgments expressed by non-experts and experts were generally similar for all the four macro-categories, with exceptions on: evaluations of dark zones (Fig.11a); distraction due to the view out (Fig. 11b); and concentration linked to the overall daylighting conditions (Fig. 11c).

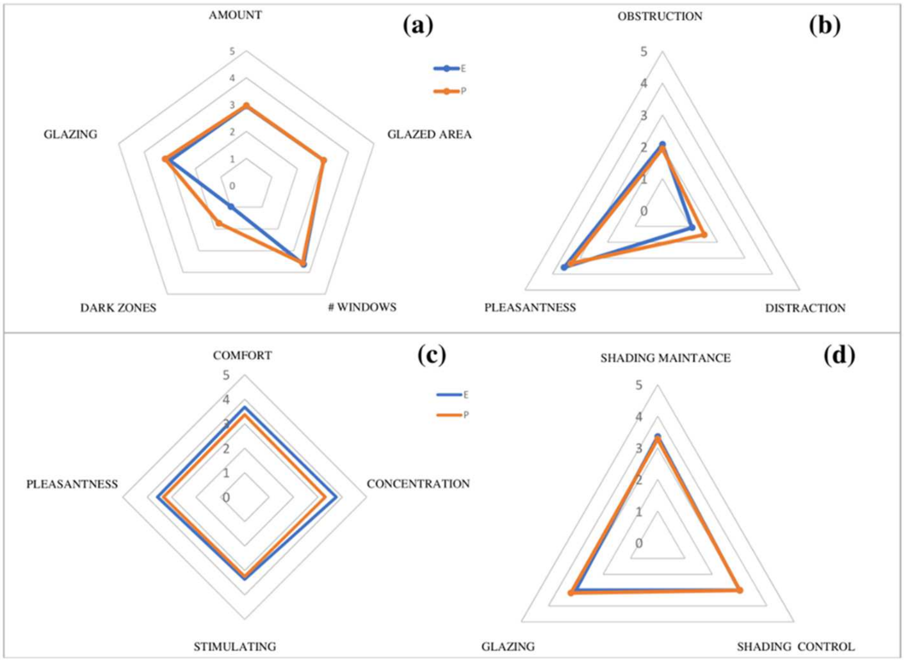

Figure 11. Comparison between experts (E, in blue) and non-experts (N, in orange) on: (a) amount of daylight; (b) quality of the view out; (c) quality of daylighting; (d) quality of the windows.

B - Statistical analyses

The Mann-Whitney U test did not show any significant differences between experts and students for most of the considered aspects. Some differences emerged only with regard to the following items: concentration due to overall daylight (U=7800.500, p=.003); distractions due to view out (U=7781.500, p=.012); and presence of dark zones (U=6320.500, p=.000). In more detail, the experts' ratings on concentration were higher than the students' ones, whereas the students rated the distractions and dark zones as significantly higher compared to experts.

RQ3: is there a relationship between DF_m and the perceived quality and quantity of daylighting in a space?

A - Descriptive analyses

Subjective assessments on daylight amount and pleasantness of the overall daylighting were compared to the DF_m of the rooms where the survey took place (Figure 12a). Besides, the WFR for each room was compared to the subjective scores that were expressed by respondents on the suitability of the window area (Figure 12b).

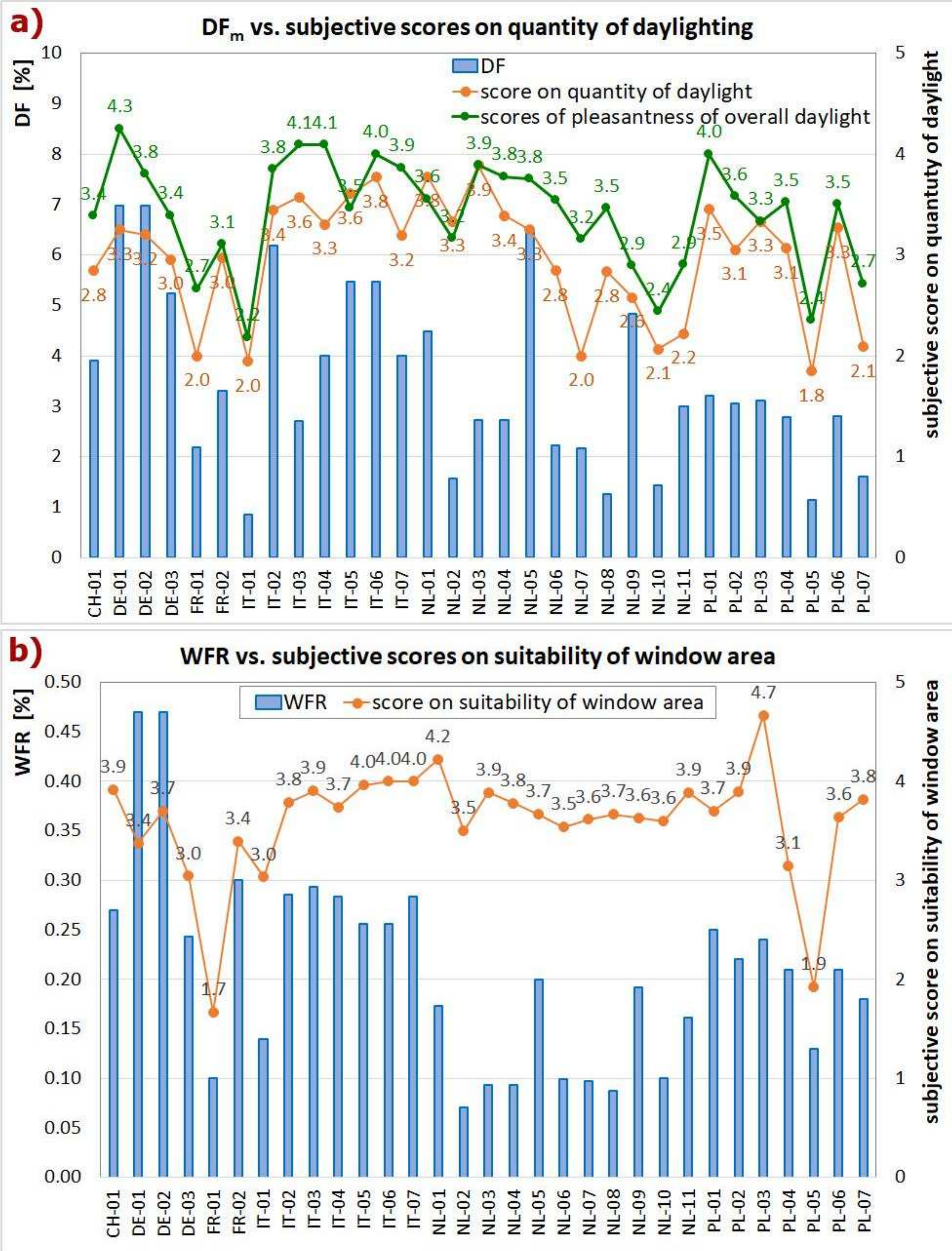

Figure 12. Objective data vs. subjective scores: (a) analytical DF_m vs. scores on the daylight amount in the room; (b) analytical DF_m vs. scores on the pleasantness of the overall daylight in the room; (c) WFR vs. subjective scores on the suitability of window area in the room considered.

As a general trend, higher subjective scores on the daylight amount perceived in the room corresponded to higher DF_m values (Fig. 12a). Apart from one case, all the rooms with DF_m > 3% received an average score above between 3 ('acceptable') and 4 ('high'). Scores above 4 were not observed, which means that daylighting was generally not considered 'too much'. This also applies to the two classrooms with DF_m > 7%. A case stands out (NL-2): an average acceptance of the daylight amount (average score of 3.33). corresponded to a relatively low DF_m value (1.57%).

The same trend was observed comparing the DF_m to the pleasantness of daylight, with subjective scores even higher than the ones expressed on the daylight amount (average score for all classrooms: 3.41 vs. 2.98).

The trend appears significantly different if subjective scores on the suitability of the window area are considered (Fig. 12b): except from two cases, the scores are over 3, also for rooms with DF_m < 3%. There are three spaces with scores above 4, which means that the window area was perceived as 'too high'. It seems therefore that the perception toward the window area is more positive compared to the perception of the daylighting admitted through that window area.

B - Statistical analyses

As far as statistical analyses are concerned, when investigating the relationship between analytical DF_m and subjective ratings on the quality of the daylight environment, the MANCOVA showed a significant main effect of DF_m ($F(3,472)=47.846$, $p=.000$) on the ratings expressed on three aspects: (i) overall quantity of daylight; (ii) daylight through glazed area; (iii) suitability of the number of windows in the room. Higher DF_m were associated with higher discomfort ratings for all the three aspects considered. This trend from statistical analyses is therefore consistent with the recommendations of the Society of Light and Lighting on DF (SLL 2011): rooms with DF_m> 5% are considered well daylit but possible glare or overheating problems may occur. However, this potential discomfort was not verified in this study, as also for rooms with DF_m > 5%, the subjective scores indicated that discomfort problems were not perceived by respondents.

RQ4: Which kind of knowledge do students have about daylighting metrics and regulations? Does it vary between bachelor and master students?

A - Descriptive analysis

Although over half (51%) of the students declared to know one or more daylighting metrics or indicators, only 21% of them used such metrics in their projects. Similarly, the number of students who reported to use daylighting calculations and software was greater (30%) than those who worked on a project that involved a daylighting assessment. It seems therefore that the knowledge of a simulation tool is not applied for developing an architectural project. Only 13% of the respondents stated to know at least one European regulation concerning daylighting, while 20% of respondents declared to know national daylighting standards. Only 16% of students reported to be familiar with other regulations on building sustainability or energy efficiency that included daylighting, solar gain and/or shading systems recommendations. Over 53% of respondents attended classes on daylighting analysis and/or calculations during their studies, but less than 6% of them participated in extra-curricular lectures on daylighting-related subjects. Figure 13 summarizes the answers stated by students in this regard.

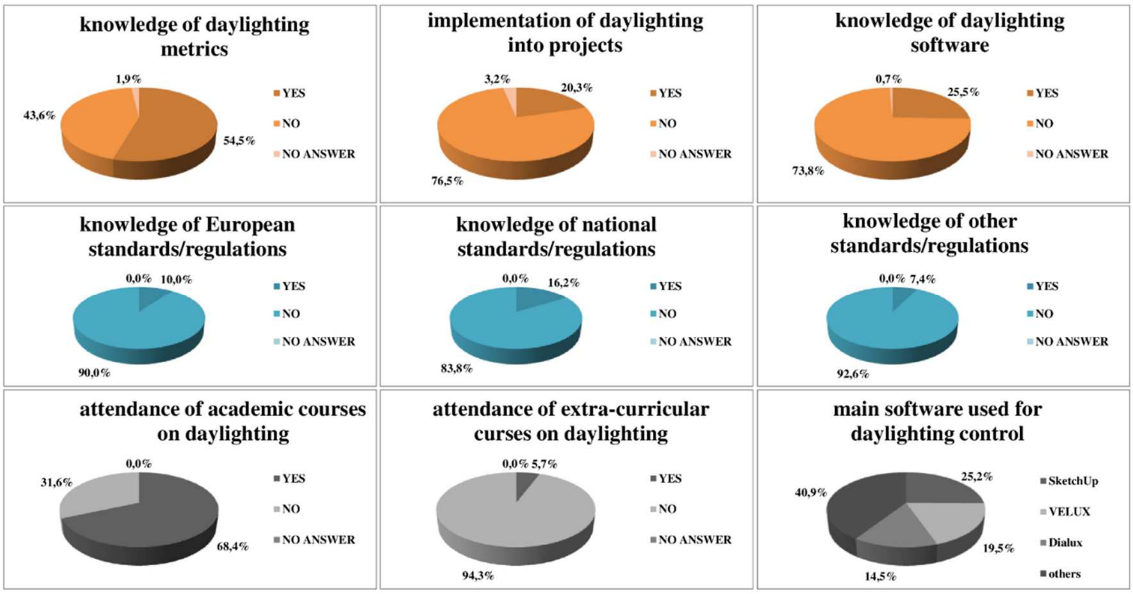

Figure 13. Statements by students on knowledge of; daylighting metrics; use of daylight calculation software; daylight regulations; and participation in daylighting courses.

As for the daylighting metrics, DF_m was the metric mostly mentioned by students, while only Italian MSc students mentioned CBDM metrics. So, on the one hand daylighting research has moved toward a climate-based daylighting modeling CBDM (Mardaljevic 2006, 2008), with the definition of new climate-based metrics (Reinhart et al 2006; Reinhart and Wienold 2011; Lo Verso et al. 2014; Costanzo et al. 2017) and the release of new regulations in replacement of DF_m (USGBC 2014; UK Education Funding Agency 2014). However, on the other hand these metrics are generally not implemented into the architectural curricula of various universities across Europe.

B - Statistical analyses

Considering the overall knowledge (metrics and regulations), when examining the links between the answers given by students (BSc vs. MSc), the chi-squared tests reported no significant associations on the knowledge of metrics (p=.929) and European regulations (p=.085). Some differences between BSc and MSc students emerged for national regulations (chi square(2)=13.586, p=.001), where BSc reported not to know any regulation more often than MSc students. The same applied also to the knowledge of other regulations (i.e. neither European nor national, chi square(2)=6.497, p=.039). Some differences between BSc and MSc students emerged also with regard to previous experience with daylight projects (chi square(2)=26.622, p=.000) and daylight modelling software (chi square(2)=25.751, p=.000), with BSc reporting less participation and experience than MSc students, as one could except.

RQ5: Do sociodemographic variables such as respondents' age and gender influence the evaluation of daylight conditions?

A - Descriptive analyses

A prevalence of females was observed in the sample (Figure 14a): 62% versus 38% of male respondents. The age distribution (Fig. 14b) showed a prevalence of people aged 21 (21%), followed by 20 (19%) and 22 (15%). These data are consistent with the degree course reported, which evidences a presence of BSc students of about 2/3 of the whole sample (Fig. 14c).

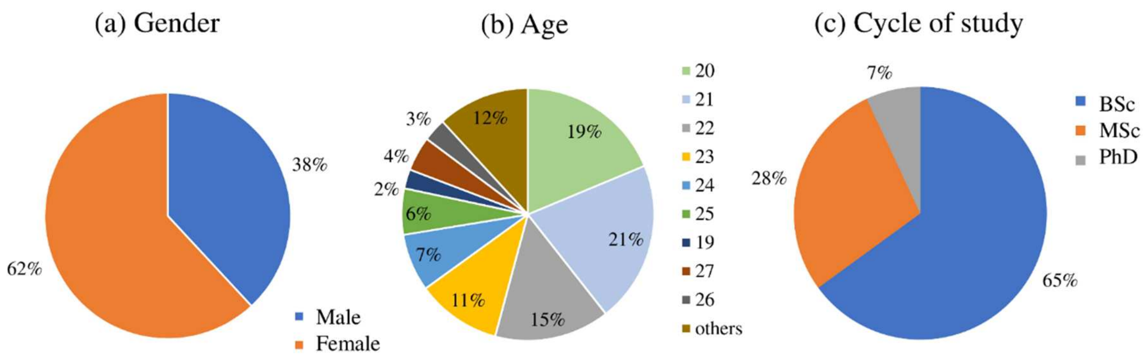

Figure 14. Sociodemographic data of the students: (a) gender; (b) age; (c) cycle of study.

B - Statistical analyses

The following section summarizes the previous QRs from a socio-demographic point of view (influence of age and gender):

- RQ1: no significant differences emerged between different ages and genders.
- RQ2: no specific socio-demographic analysis was carried out on the sample of non-experts.
- RQ3: statistical analyses showed no significant difference on the scores attributed to quantity of daylight and overall pleasantness of a daylit space.
- RQ4: there is a correlation between the enrolment year and the participants' age. Therefore, this effect seems mainly due to a sample of students with a prevalence of bachelor's degrees with an age between 19 and 22 years.

5. Discussion

The following considerations may be extracted from the results.

Influence of sky conditions and distance from windows on comfort and mood (RQ1), including sociodemographic effects (RQ5).

Both the statistical and descriptive analysis confirm an influence of sky conditions and distance from windows on comfort and mood reported by respondents.

Daylight comfort was rated with higher scores in the presence of clear skies. Although higher comfort scores were reported in the proximity of windows, this trend was not observed for positions 'very close' to window, which can be affected by direct sunlight.

A significant correlation between sky condition and mood was not verified. This is probably due to the fact that mood is to a higher degree the result of a combination of objective-environmental and subjective-psychological factors, while comfort is more directly influenced by the environmental conditions within the examined space.

As noted by Veitch and Gifford (1996), mood is typically influenced by a number of interconnected factors and does not seem to be dependent on the daylight condition in a univocal way. Similarly, Galasiu and Veitch (2006) and Wang and Boubekri (2010) observed a significant correlation between positive mood (very positive and positive) and daylight comfort. The negative mood judgments (negative and very negative) occurred for positions further from windows.

Congruence of judgments on daylighting perception of experts and non-experts (RQ2)

The congruence of judgements between experts and non-experts regarding the perception of a daylit space was verified in the present study, as it was in the earlier study (Giuliani et al. 2017). This seems to demonstrate that the perception of the quantity of daylighting is similar for the two groups. The consistency is quite robust, particularly for questions regarding quantity of daylight, quality of the view to the outside, and control and maintenance conditions of windows. Less agreement between experts and non-experts was observed regarding the quality of daylighting in terms of its pleasantness, of comfort, of concentration and stimulation provided by daylighting within the space considered. In this case, students expressed more negative judgments than experts. This can be interpreted in a twofold manner:

- experts can detect subtle aspects of comfort more easily thanks to their experience and expertise, which may have somehow resulted in more positive judgments
- students had a more difficult visual (and cognitive) task to perform, as they were involved in filling the questionnaire as part of a university lecture, which requires a high degree of attention and cognitive capacities. This leads to higher expectations regarding the (day)lighting conditions. On the other hand, experts are performing a 'standard' activity, i.e. giving a lecture, which is probably less 'stressing' than it is for students and thus results in a higher acceptance of the daylight conditions.

Average Daylight Factor DF_m and judgments on perception (RQ3)

Statistical analyses showed a significant link between the analytical DF_m and subjective positive judgments. It is interesting to stress that in almost all rooms (with one exception only) where DF_m meets the minimum standard requirement of 3%, the quantity of daylight was averagely rated between 3 ('acceptable') and 4 ('high'), without any scores over 4 ('too much' daylighting, which can cause discomfort). In spite of the critics toward the DF_m, due to its inherent limitations (it is a metric conceived for countries where overcast skies are the most common during the course of a year), in this study this metric appears a reliable indicator for the quantity of daylighting in a space (especially for rooms with DF_m > 3%), based on the judgments expressed by the respondents. Differently, the upper limit according to which DF_m > 5% may be associated with the presence of direct sunlight in the room (and consequently visual/thermal discomfort) did not find any confirmation in this study. A similar result was also found in another study carried out by some of the authors in healthcare buildings (Lo Verso et al. 2015). Furthermore, for almost all the classrooms the scores on pleasantness of daylight were even higher (average score for all the classrooms: 3.41 vs. 2.98 – see Figure 12). This shows that other factors, besides the mere daylight amount, contribute to the individual perception of a daylit space (Veitch and Galasiu 2012; Knoop et al. 2019): in this regard, a key role is played by colors and luminance of room surfaces (Tregenza 1999; Simm and Coley 2011), quality of the view out (Hamzah and Lau 2016), room shape (Bezjak et al. 2003), luminance of the sky dome (Kittler 2007), type and effectiveness of shading systems (Yener 2002). Also, besides lighting and architectural aspects, other factors concerned with users' preferences and lifestyle (in terms for instance of stress, sleep quality and so forth) are crucial in determining the mood of people (van Bommel 2006; Aarts et al. 2018).

Knowledge and Training (RQ4)

More than 73% of the surveyed students stated to have participated in lectures on daylighting and to know at least one daylighting indicator or metric. However, only 21% of them used daylighting modelling and calculation tools in their design projects.

Among the indicators, the DF_m is the most commonly mentioned, while advanced indicators such as climate-based daylighting metrics (CBDM). Another metric which was mentioned was the WFR. Nevertheless, this is a ventilation rather than a daylighting criterion, widely used in the common design practice due to its simplicity.

Other metrics that were mentioned as daylighting indicators were: illuminance (sometimes referred to by its unit 'lx' rather than by 'illuminance') or luminous flux. This shows that the concept of 'daylighting metric/indicator' itself was not very well understood by a number of respondents.

As far as the knowledge of daylighting standards and/or norms is concerned, the results indicate a slightly higher level of knowledge than what found in previous DAYKE stages, but the level is still very low. In addition, an increase in the knowledge was observed for MSc compared to BSc.

Such a lack of knowledge regarding norms and requirements may therefore lead to a limited implementation of daylighting into the architectural design process, or to non-conscious design decisions, which unfortunately may not allow the designers to exploit the full potential of daylighting. Moreover, the daylighting skills learned in class seem to remain at a theoretical stage and with limited implementation in the design project.

One of the lesson learned within the DAYKE project is that in the frame of an architecture practice that evolves more and more toward the concept of 'sustainable architecture' (a sustainability which is social, economic and technical/physical (Fregonara et al 2017)), too little is being done to promote the culture of daylighting as a driving factor of sustainability in buildings. Considering the difficulties in introducing modifications in university curricula, single teachers (especially in the technology/building physics areas) could introduce dedicated lectures to increase the knowledge of daylighting aspects, metrics and regulations.

Relationship between expertise and perception of the daylit space

Although the basis of the investigation was extended and refined, new findings of Q-AR seem to confirm what was observed in the previous survey Q-A. In short, the similarities of judgments expressed by experts and non-experts (QR2) combined with low levels of daylighting knowledge (QR2) seems therefore confirmed that the daylighting perception is not influenced by the individual knowledge on the subject.

Considerations about the method: merits and limits

The DAYKE project is a wide study on the topic of daylighting knowledge, perception, and education in Europe. This can be considered the main merit of this investigation as to the authors' knowledge, no such attempt has been done within the research community so far. In this sense, one of the strengths of the project is the development of innovative questionnaires, specifically conceived to incorporate the views of both an academic and non-academic population. Moving forward to the next stages (Stage 2) of the project, it is expected that this research can contribute to raise awareness at how knowledge gained in academia is then transferred into the profession. The results from DAYKE may also help to identify differences regarding university curricula across Europe and allow the definition of strategies to tackle better approaches to the education of the future European lighting and daylighting design professionals (Stage 3).

As far as the limitations of the research are concerned, it is worth stressing that the answers provided by the participants may be influenced by a number of personal/private aspects (especially with regards to the mood). The questionnaire was administered only once per class, so the preferences and the judgments expressed by the respondents apply to specific sky conditions, time of day and season of the year. It would be worth resubmitting the questionnaire to the same class in different sky conditions or in a different time of the year.

6. Conclusions and future steps

The DAYKE project has been set with the main goal of investigating to what extent the key topic of building daylighting is present in architectural education in Europe, including the knowledge of metrics, regulations and standards and the perception of the daylit space.

The results of DAYKE survey presented in this paper illustrates 4 main trends:

(1) it seems that comfort and mood are affected by the perception of sky conditions and by the distance from windows (sitting position);

(2) the average daylight factor showed a good agreement with subjective judgments on the amount of daylight in a space, especially when the standard requirement of DFm > 3% is fulfilled. Actually, higher DFm was associated with judgments expressed by respondents on the daylight amount between 'acceptable and 'high';

(3) the congruence between the judgments of the experts and non-experts about the perception of daylit environment, already observed in an earlier study, seems to be confirmed, except for the quality of daylighting, which requires further study;

(4) it can be noted a vague and incomplete knowledge of metrics and regulation among architecture students about regulations and standards despite the fact that more than

2/3 of the surveyed students had participated in courses that introduced daylighting design.

The collection and analysis of the Q-AR data is still ongoing and a new survey for professionals (Q-B) was developed and submitted as a pre-test (DAYKE stage 2). This will be useful to explore to what extent daylighting is implemented into the current professional design process.

As a final conclusion, the authors strongly encourage that the topic of daylighting, which is a key aspect to consider for both indoor environmental quality and energy saving issues, is given much more importance at different levels and by different stakeholders, from universities to professional groups. Dedicated courses should be offered, also with the aim of implementing the new daylight metrics based on CBDM or circadian evaluations into the design practice.

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