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Lighting systems and users interactions in classrooms and laboratory rooms

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ABSTRACT
In Brazil, there has been an increase in the use of certifications designed to assess and improve building performance. Despite these advances, there is still little knowledge concerning the buildings' post-occupancy. Thus, the present work aimed to evaluate the occupants' behaviour regarding the use of lighting and internal shading devices. Classrooms and laboratories at UFMG Architecture and Design School were used as case study. The main objective was to analyse how a cycle of influences works: how occupants influence energy consumption and act in relation to the buildings systems, as well as how the building and the internal systems influence the occupants' behaviour. Firstly, daylighting and artificial lighting conditions of the rooms were diagnosed. As for the occupants' behaviour analysis in loco, observations were made to evaluate barriers and potentials in the systems use. Afterwards, changes were made in the lighting circuits division, in the curtain types and informative posters were installed in the studied rooms. The results showed that there is a hierarchy in the use of classroom systems, in which professors are the main controllers and that in laboratories the systems use is well distributed among occupants. It was considered that the original evaluated systems did not meet the occupants' expectations in general, so changes were proposed. The changes proved to be efficient once the interaction of users to the systems improved in quality and in number. This research allowed to infer that a more occupant-centered design leads to a more efficient use of spaces.

KEYWORDS
Occupants' behaviour, Energy Efficiency, Buildings performance, School Building.

INTRODUCTION
Buildings account for approximately 40% of the world energy consumption (IEA, 2013) and for 50.8% of all the electricity consumed in Brazil (EPE, 2016). According to PROCEL (2005), lighting represents 22% of this consumption to commercial buildings and 23% to public buildings. The emergence of building certifications and the effort that has been observed nowadays regarding this issue, in Brazil and in the world, points to visible advances for more efficient buildings. However, little is known about the operation of a cycle of influences that is essential for the buildings energy efficiency: how occupants influence the efficiency and comfort of buildings and how buildings as proposed influence the occupants' behaviour.

Lindelof and Morel (2006) described the results of an analysis carried out in Switzerland. They concluded that after the occupants' arrival and departure periods in the office the lighting system was only turned on again in cases of extreme discomfort. The authors believe that this behaviour was a consequence of the position of the light switches, which were located near the offices entrance door and not near the workers' tables. Mahdavi et al (2008) described a empirical study of occupant's operation of lighting and shading systems in Austria office buildings. They concluded that patterns of user control behaviour depends on indoor and outdoor environmental parameters, as the illuminance and the solar radiation incidence. They also realized that there is a relationship between occupancy and lighting operation. Based on a literature survey on drivers and models, Fabi, Andersen and Corgnati (2015) reinforced that the probability of light-switching is highly related to people's arrival or departure in the offices. They also concluded that it is essential to consider the occupants' individuality in order to understand different behaviours, as some individuals consider daylighting when switching on the lights, whereas other occupants switch on the lights independently of daylighting. Reinhart and Voss (2003), while conducting a survey at an office building where one or two people worked, in Germany, concluded that groups of individuals follow a very similar behaviour, whereas isolated individuals follow more diverse patterns. The authors verified that all building occupants considered daylight, which could confirm the influence of architectural conception and lighting system proposed for the building on the differentiated occupants' behaviour.

Jennings et al (1999), after testing different lighting control technologies in an office building in San Francisco, concluded that the lighting requirements of occupants depend on their type of work. Daylight dimming, as an example, showed to be more adequate for workers who stay at their desks all day. Moore, Carter and Slater (2003) also concluded, after a long-term study which monitored the switching behaviour in offices where occupants could vary the level of illuminance on their working areas, that user controlled lighting systems could save energy, keeping the occupant's comfort. LEED Reference Guide for Green Building Design and Construction (USGREEN BUILDING COUNCIL, 2009) indicates that independent lighting controls should ensure occupants' autonomy in changing them in order to promote comfort, productivity and well-being. It also indicates that windows must be treated in order to allow appropriate levels of illumination without disrupting projections.

Gyberg and Palm (2009), in a study carried out on residential buildings, concluded that to change people's behaviour, it is necessary to ensure that the choices can be made by the individual, by the provision of design alternatives that do not affect their lifestyle. On the other hand, after analysing the use of curtains, windows and lamps in offices in Austria, Mahdavi and Proglhof (2009) verified how difficult it is to estimate a single individual's behaviour. Norman (2010) argues that bad projects, created for people the way designers would like them to be and not as they really are, constitute the real causes of design inefficiency. On the other hand, ISO 50.001 (2011) presents a methodology based on a continuous improvement model - "Plan-Do-Check-Act" - which points out the need for constant checks on installed systems to guarantee their quality, efficiency and understanding by their users.

Therefore, the present research aimed to verify the occupants' behaviour regarding artificial and daylighting systems, by identifying the barriers and potentialities of installed systems and proposing changes to enhance lighting and daylighting systems use.

METHODS

Case Study: Architecture and Design School - UFMG

For the present research, three classrooms and three laboratory rooms of the Environmental Comfort and Energy Efficiency in the Built Environment Laboratory (LABCON) of the Architecture and Design School of the Federal University of Minas Gerais (EAD-UFMG) were investigated. The rooms presented windows faced to different orientations and solar control elements. Classroom A has windows facing the North and South façade, translucent curtains in all windows and external shading devices to the North (Belo Horizonte is in the South hemisphere). Classroom B has windows oriented East façade and presented blackout curtains.

Classroom C windows faced West and besides blackout curtains presented the windows painted in white which indicated extreme user discomfort. The three rooms of the Laboratory face West and presented white metallic horizontal venetian blinds (Figure 1). All studied rooms presented internal controls for the artificial lighting switching, located next to the doors.

Figure1 – Classrooms A, B e C and laboratory rooms 01, 02 e 03, respectively.

In loco Observation and daylighting analysis

The occupants' behaviour was investigated by a group of 3 *shadow observers* (an observer was always present in each of the studied rooms but not identified) during a total period of 161 days divided according to the classes schedule and the Laboratory occupation hours in the mornings and afternoons. Classroom A was observed in 31 classes (totalizing 136 hours); Classroom B in 34 classes (totalizing 111 hours); Classroom C in 21 classes (totalizing 56 hours); Room 1 was observed for 24 periods (totalizing 129 hours); Room 2 for 27 periods (totalizing 145 hours); Room 3 for 24 periods (totalizing 136 hours). For the data collection, checklists were fulfilled by each observer, that covered six aspects: General Characteristics of the room; Visual activities; Occupation; Lighting system status; Solar Incidence in the work plane; control systems and Use of windows. The observations were divided into four parts: a) rooms as originally configured, b) after changes were made in the lighting circuits, c) after the substitution of the solar shading devices and d) after the insertion of informative posters.

The daylight autonomy (DA) was analysed through simulations in Daysim software to help analyse the potential use of daylighting in the studied rooms.

Changes carried out in the lighting control systems and in the window shading devices

The observations allowed the researches to point out barriers and potentialities of the existing systems. After that, changes were made in three stages: 1) Lighting system: circuit division modifications to allow the integrated use of daylighting and artificial lighting and light switches reorganization to better express the spatial distribution of the luminaires. 2) Solar shading devices: replacement of the blackout curtains for venetian blinds. The purpose of this change was to allow greater availability of daylight and to broaden the possibilities of user interaction with the system by changing the fins position. 3) Insertion of informative posters: this step was intended to fill up the lack of readability of the existing systems and to test the effectiveness of graphic representations of the ambient systems in informing users how to better use the venetian blinds and lighting switches. At each change, a new diagnosis was made to verify the effectiveness of the changes and the need for further modifications in the systems.

RESULTS

In the first stage, when rooms were observed as originally configured, Classroom A and the laboratory rooms presented solar shading devices considered to be effective in controlling the sun incidence indoors and the artificial lighting was adequately integrated with daylighting. On the other hand, classrooms B and C presented no integration with daylighting; besides that, the blackout curtains obstructed from 30 to 50% the window area. Daylight simulations showed that in classroom A the luminaires located near the windows could be turned off during the whole morning and part of the afternoon. Computer simulations also showed that if the blackout curtains were substituted by internal venetian blinds, in Classrooms B and C, the Daylight Autonomy near the window would be superior to 80% in all classrooms when there was no sunlight incidence in the façade.

For the laboratory offices, the use of integrated daylighting and artificial lighting systems showed greater potential in the morning during the first stage of the observations. In the afternoon, the venetian blinds tended to remain closed or partially closed in order to control sunlight radiation incidence once their windows face West. The observations pointed out that the professors were the main controllers of the lighting systems in the classrooms and that changes occurred mainly upon arriving and leaving the rooms. Changes during classes occurred only when the lack of lighting was noticed or when a change in the visual task was necessary (mainly for data-show use). In the laboratory rooms, there was no pre-defined controller and more changes were noticed in the lighting systems associated with the arrival of new occupants.

In the second stage of observations, after the changes to enhance the systems operation in classrooms B and C were made, it was found that the use of integrated daylighting and artificial lighting became more significant in both classrooms. The luminaires located near the windows remained turned off in 50% and in 67% of the observed classes in classrooms B and C.

Finally, after informative posters were fixed, luminaires association with daylighting enhanced and luminaires located near the windows remained turned off in 87% and in 67% of the observations in classrooms B and C, respectively. As for the LABCON rooms, luminaires located near the window were turned off in 34% of the observed days and the position of venetian blinds was modified in more than 50% of all observations. For classroom A considered to be the better daylit room in the study, on the other hand, the occupant behaviour was not significantly altered.

Regarding the use of solar shading devices, a tendency to preferably open the venetian blinds or curtains positioned on the movable parts of the windows was observed. This was mainly due to ventilation needs than to the intention of enhancing daylighting. After the substitution of blackout curtains to venetian blinds, an increase of difficulties in using this system was noticed. There was also an increase in the number of changes made in the venetian blinds especially during the classes where the data-show was used. The difficulties in the use of the blinds were reduced after the informative posters installation.

DISCUSSIONS

The observations made reinforced the conclusions drawn by Lindelof and Morel (2006), who claimed that occupants tend to act in lighting systems upon arriving and leaving the rooms and that during this interval they only act on these systems when they feel disturbed or when there are changes in the visual task.

The lack of a user behaviour pattern in LABCON rooms confirmed the findings of Reinhart and Voss (2003), who observed that behaviours of groups of individuals are standardized, whereas isolated individuals follow a more diverse pattern of behaviour. While in the classrooms the use of the lighting system was mostly associated with the type of class that took place and data-show use, in the laboratory rooms the use of the lighting systems was more related to the room occupation.

It was verified that, accordingly to the LEED Reference Guide, when the room presents different control options for the lighting systems, usage is enhanced. This finding also confirms the conclusions by Gyberg and Palm (2009) that individuals should have choices. The alterations made in the original systems enhanced occupants' behaviour, reinforcing Norman's (2010) conclusion that the inefficient use is a consequence of project failures. The significant increase in the number of observed cases in which the occupants had difficulty in using the venetian blinds, after they substituted blackout curtains, showed that the installed system was not intuitive enough to its users, confirming once again Norman's (2010) conclusions.

Lindelof and Morel (2006) statement in that users of rooms act on systems when they are disturbed was confirmed in all analysed rooms, once curtains and venetian blinds were closed when there was incidence of direct solar radiation in the work planes or desks. In this way, it was verified that in favourable orientations or when external shading devices were present, there were fewer actions in the solar incidence control system.

Observations also reinforced the validity of the model of continuous improvement proposed in ISO 50.001 (2011), as it was verified that each system change was correspondent to a change in user behaviour.

The study also showed the importance of detailing systems. The use of venetian blinds was an interesting alternative to encourage the use of daylight integrated with artificial lighting. As observed, the modifications in the curtains were made only to enable the opening of the windows for ventilation and not to improve daylighting. So, testing venetian blinds divided in 2 parts and not in 4 parts, as the original venetian blinds, could be a great alternative, as when they were opened for ventilation purposes, daylighting would automatically enhanced as the fixed parts of the windows would also be uncovered. This new system would probably work well in rooms with lower problems of direct sun incidence in the work planes.

CONCLUSIONS

The present study showed that the usage efficiency of the buildings depends greatly in the architectural and interior systems design. If users tend to act on existing systems either when arriving or leaving internal spaces or when they are disturbed, it is concluded that the best designs are those which demand the minimum number of changes by users, especially when entering the rooms. Therefore, designers should be aware of the many factors that may influence the user behaviour and pay special attention to the first occupancy hours as they may determine if lighting systems will need to be turned on. The correct choice of room orientation and proposition of an adequate solar control system, consistent with the activities that will be carried out, is a point that must be observed. External elements that guarantee visual and thermal comfort showed to be preferable than internal shading devices that require special handling by the occupants.

In the study case, LEED recommendations contributed to the improvement of the use of the lighting system, confirming that not only the occupants influence the efficiency of the proposed system, but the way the system is proposed also influences the behaviour of the occupants.

It was observed, from the methodology applied in this work – which consisted in performing changes and re-evaluating the space use after the changes – that the process of working in a cycle of continuous improvement is fundamental to improve the quality of existing systems. Working in a cycle of continuous improvement is also essential to understand the relations between systems' use and user behaviour.

Finally, it is recognized that projects are not static, as the needs change and since users of each space are different. When retrofitting a space, the decisions made must contemplate the resulting quality of the space and especially the users' well-being. It is only by observing the occupants' behaviour that patterns can be understood and it is only after understanding them that good projects can be designed. The way the design is thought influences greatly how users act in a particular building.

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