Customizing sustainable evidence based design: A daylight study in south semi-private patient rooms

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\textbf{A B S T R A C T}

A sustainable healing environment is fundamental in healthcare facilities. However, local terrain, climatic and cultural particularities entail some international differentiation among the respective architectural principles. Aim of this paper is to contribute in documenting the Greek experience and use this knowledge to study evidence based design architectural concepts applicable to both new and existing facilities. To this end, a post occupancy evaluation of a representative Athenian hospital was performed. A sample of semi-private south patient rooms was studied using architectural documentation, questionnaire survey, as well as daylight and energy simulations. Findings were leveraged in researching concepts that would enhance the healing potential of this setting, but also mitigate specific adverse environmental conditions. These concepts were then evaluated in terms of energy demand and their cost implications. The findings indicated that the patient room visual environment evaluation was not significantly different among patients and visitors. The analysis ascertained some discrepancy between objective and subjective evaluation and established an interrelationship between daylight and view evaluation. Following these cues, an external shading system was designed, which would safeguard the merits of the therapeutic sunshine and view. Results verified the challenging task of balancing resource usage with overall user comfort.

\textit{Keywords:} healing environment, evidence based design, sustainability, post occupancy evaluation, daylight

1. \textbf{Introduction}

Holistic sustainability is a dynamic between international research and best practice on the one hand and local particularities of terrain, climate, culture and society on the other. Thus energy efficient buildings not responding to cultural values will most likely fail to remain relative or functional to the population they were designed for and hence be rendered useless, requiring significant adjustments or even replacement (McMinn & Polo, 2006, as cited in Guenther & Vittori, 2006).

One of the most challenging tasks of healthcare architecture is to create a sustainable healing environment. The physical environment and patient health and well-being interrelationship had already been well acknowledged in Asclepieia (Christopoulou - Aletra, Togia & Varlami, 2010). Recent research, however, seems to address work environments and schools more frequently than hospitals, where optimal environmental conditions are essential to the overall health of its users (Choi, Beltran & Kim, 2012). Nevertheless, the overall research establishing this multi-level relationship is undisputed (Ulrich et al., 2008).

Harris, McBride, Ross, & Curtis (2002) acknowledged three categories of environment settings; first, the permanent architectural, including features like spatial layout and window location, second the less permanent architectural, such as colors and third the environmental aspects, comprising ambient qualities like light and noise. If not understood and addressed properly, ambience could feature unpredictable or uncontrollable extreme conditions and therefore be rendered stressful (Evans & Cohen, 1987; Topf, 1994).

The need for architects to be more engaged in this interdisciplinary process is crucial, since healthcare environments comprise spatial interrelations of all ambient features investigated in relevant studies, since these

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appear to be carried out mostly by environmental psychologists (Griffin, 1992; Wilson, 1972). Indeed, there seems to be a considerable overlap between evidence-based design (EBD) and sustainable design (SD), which must be explored (e.g. Rostenberg, 2009).

In this context, natural light is a powerful architectural ambient feature. Constrained as bioclimatic attributes, daylight and sunlight are decisive contributing factors, particularly in southern orientations of the northern hemisphere. Notwithstanding orientation, window geometry and space layout have respective significant roles in defining sunlight penetration and the utilization thereof. For instance, southern windows will most likely be ineffective, if not featuring proper shading (e.g. Ito, Yuming, Watanabe and Tanabe, 2008). At the same time, daylight is inextricably linked to well-being. Humans are influenced by weather and relate sunshine to positive mood (Beute & de Kort, 2013). Moreover, the interaction between sunshine and skin triggers vitamin D production, which is linked to the secretion of serotonin, a mood-related neurotransmitter (Landsdowne & Provost, 1998). The literature concerning healthcare settings suggests that sunshine is the ambient feature with the most convincing outcomes and is correlated with predominantly positive effects on the length of stay, mortality rate, perceived stress and pain (Dijkstra, Pieterse & Pruyn, 2006, Ulrich et al, 2008). Bright hospital rooms are more beneficiary than dim spaces, regarding health (e.g. Beauchemin & Hays, 1998), medication intake and state of mind on discharge (Walch et al., 2005). Nonetheless, specific health effects of daylight are more often found in researching on specific medical conditions than in trying to establish the need for healthy indoor environments (Aries et al., 2015).

Investigating overall user perception is tie-in to effective user-centered design, since aiming to create spaces for present and future needs and preferences should take user experience into serious consideration (Andrade, Lima, Fornara & Bonaiuto, 2012). For instance, scholars already underline the need to broaden the definition of a quality day-lit setting to include spatial characteristics and user responses (Wang & Boubekri, 2011). Other researchers argue that international standards must address subjective evaluations overlooked in relevant handbooks, since different people react differently to the quantitative and qualitative daylight aspects (Meir, Garb, Jiao & Cicelsky, 2009). Healthcare settings prove even more challenging, since the two main user groups, i.e. patients and staff, experience space differently and have according beliefs and expectations from it (Huisman, Morales, van Hoof & Kort, 2012). Moreover, Zimring, Reizenstein & Michelson (1987) further suggested that “visitors”, the user group including patient family members and caretakers, was, until recently, misunderstood and not properly addressed.

Notwithstanding user perception, other issues particular to demographic or social parameters and aspects of terrain must also be considered. For example, Botma and Hoekstra (2006) demonstrated that not all EBD findings originating in the U.S, where the majority of research still comes from, are applicable internationally. After all, behavior is a human response to external environment and internal needs (Porteous, 1977) and preference is influenced by personal experiences and societal values (Beute and de Kort, 2013).

These issues underline the relativity of architectural design, especially in healthcare. Even though the life span of a hospital building counts approximately sixty-five years, timely replacement is in most cases not feasible, mainly due to resource limitations, translating in a healthcare unit lifetime of more than a hundred years (Pützep, 1979, p. 139). It is thus reasonable to assume that the future need to retrofit existing hospitals according to international standards will be more frequent than to construct new facilities (Hofrichter, 2006). Hence differences in building typology, which is responsible for major resource consumption impact, should be identified, documented and addressed (Guenther & Vittori, 2008, p. 319) and the need to collect empirical data and form national architectural databases of hospital construction is evident (Huijsman, 2006).

To the extent that Greece is concerned, current national building regulations aim to integrate a comprehensive appraisal of the environmental and ecological footprint, comprising energy performance studies, evaluation and inspection (Hellenic Ministry of Economy and Hellenic Ministry for the Environment, 2010). Although energy consumption mitigation is extensively addressed, subjective assessment and human response are not factored in or acknowledged for their fundamental importance in specific physical settings, like hospitals. Moreover, the regional structure of the Greek healthcare buildings is already fully developed, putting the notion of future retrofitting and the need of proper holistic architectural documentation in critical perspective. In addition, the rationale developed by Huijsman (2006) could be extended to topics such as user experience and evaluation. To this end, previous work of
this team introduced a first appraisal of four hospital building types, i.e. the simple linear model, the curved linear model, the cross linear model and the double “L” model, and underlined the need to carry out thorough post-occupancy evaluations (POEs), which should include user spatial and environmental evaluation (Sklavou and Tzouvadakis, 2015b).

As mentioned previously, there is an overall indication that architectural research addresses healthcare settings less than other building types (Choi, Beltran & Kim, 2012), whereas the impact of the physical environment on humans is studied more frequently with respect to environmental psychology than any other discipline (Griffin, 1992; Wilson, 1972). Moreover, with the exception of few exemplary initiatives, architectural education and research of hospitals in Greece, both academic and professional is absent (Sklavou and Tzouvadakis, 2015a). In this context, an architectural research project regarding healthcare environments in Greece comprises inherent challenging limitations. At the same time, it can contribute essential information and introductory knowledge towards the creation of national architectural databases, regarding objective data like building documentation and assessment, as well as subjective issues, such as user perception.

This paper is a POE study discussing visual environment issues of patient rooms in one of the building types mentioned above (Sklavou and Tzouvadakis, 2015a). Focusing on daylight evaluation, it leverages user perception to study retrofitting design concepts that will contribute to a holistic sustainable healing environment. Because of the inferential cues attributed to this building and the absence of a consistent and comprehensive national architectural database (Sklavou and Tzouvadakis, 2015b), general findings can also be construed as groundwork for future work to build on. The study comprises two sections, a field and experimental, which will be presented consecutively.

2. Field study

2.1. Methods

2.1.1. Location and Participants

A hospital comprising features within a wide range of common architectural characteristics of Greek hospitals was selected (see images 1,2 and table 1). The selection was further facilitated by the willingness and cooperation of the hospital’s staff and administration. Our research interest focused on two questions.

1. Did patients evaluate their surroundings differently from visitors?

2. Is there an interrelationship between daylight evaluation and the overall assessment of the patient room visual environment?

Image 1. The selected hospital with regard to (a) its urban environment and (b) the main nursing unit building. The study was conducted on the semi–private patient rooms of the sixth floor.
2.1.2. Instruments

The questionnaire used in this survey was a modified version of a questionnaire developed, validated and used by the International Energy Agency (Hygge, 1999). Assuming a hand-out version would receive little engagement, the questionnaire was formatted to be conducted as on-site personal interview. This format adjustment, as well as translation in Greek and revision with respect to EBD literature was done by the authors of this study. Notwithstanding demographic characteristic documentation, such as patient length of stay until the time of interview or visitor length of stay per day, age group and sex, the resulting questionnaire comprised categorical and dichotomous questions (see figure 1). With regard to their content, the questions were organized according to Harris (Harris et al., 2002). Permanent architectural feature appraisal comprised spatial density and window size, whereas and non-permanent feature assessment addressed color and shading. Environmental evaluation focused on daylight, sunlight, visual discomfort, window features, both positive (window positive features - w.p.f.) as well as negative (window negative features – w.n.f.) and view issues (see figure 1, 2 and table 3).

2.1.3. Procedure

The study took place in the orthopedic patient rooms of the sixth floor of the main nursing unit building (image 1b and image 2). It was essential not to disturb the patients or impede the staff. The team thus entered patient rooms only after staff advisement. The staff suggestions included patients experiencing low levels of pain, either due to the nature of their condition, or to the stage of their recovery. Except the interview with consenting patients and visitors, the interviewer would also perform an architectural documentation. Personal notes, sketches and photographs were used to note spatial particularities, e.g. state of window or curtain, as well as document, among others, the participant’s location and body position (Image 3).

2.1.4. Data Analysis

Data analysis was performed in SPSS Statistics. The first step entailed a descriptive documentation of the overall architectural and environmental evaluation, as elaborated above, in the instrument section. Figure 1 shows the
comparative evaluation of patients and visitors. Figure 1a shows categorical questions and figure 1b shows dichotomous questions. The second step addressed the investigation of the research questions. Figure 2 shows the respective framework. To study the first research question, i.e. if patients evaluated their surroundings differently from visitors, the variable “user group” was maintained as independent and the rest of the architectural and environmental parameters were considered as dependent. A similar approach was maintained in studying the second research question, i.e. the interrelationship between daylight parameters and the overall environment appraisal. In order to gain as good of an insight into user experience as possible, patients and visitors were studied separately, notwithstanding that important differences among them would be established in the investigation of the user group comparison. The statistical relationships was documented with chi – square exact tests of independence, its nature with frequencies acquired from the relevant crosstabs, and its effect size with Crammer’s V ($\Phi_{\text{Crammer}}$) or Phi ($\Phi$) coefficients. The chosen level of significance was $p < .05$, although $p < .01$ is also indicated.

<table>
<thead>
<tr>
<th>Table 1. Patient room spatial and window properties</th>
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<tr>
<td>Room area (m$^2$)</td>
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<td>Main room area (m$^2$) (WC and hall excluded)</td>
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<td>Main room area per patient (m$^2$)</td>
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<td>Window area (m$^2$)</td>
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An unfortunate limitation was not being able to include nursing staff responses in the analysis. Although the sum of the survey does take personnel into account, inclusion and exclusion criteria of this study resulted in a sample of n = 18 staff observations. Additionally, the nature of the interview, i.e. oral, raised some questions regarding the extent of spontaneity and sincerity of the responses, since answers from one interviewee could influence their neighbor’s overall opinion. Nonetheless, lack of privacy is an inherent feature of semi-private patient rooms (e.g. Ulrich, 2008) and other forms of survey would likely not acquire the same degree of participation. A further limitation concerns the inferential value of the findings. Due to the nature of the site and sample selection, results from this survey address the specific case study. However, there is considerable compatibility between this hospital and other Greek healthcare facilities. Besides, to the best of our knowledge, there is a significant absence of such studies regarding Greek healthcare environments (Sklavou & Tzouvdakis, 2012, Sklavou and Tzouvdakis, 2015b). In this context, present findings could offer inferential cues and be used conservatively as documentation of the Greek experience, until this gap has been properly addressed.

### 2.2. Results

In total, n = 138 people participated in the survey. Of those, n = 76 (f = 55.1%) were patients and n = 62 (f = 44.9%) were visitors or patient family members. Regarding the sum of the participants, were f = 52.9% were male and were f = 47.1% were women. Moreover, 21.7% were under 30 years old, 13.8% were between 30 and 39, 17.4% were between 40 and 49, 15.9% were between 50 and 59 and 31.2% were over 60 years old.
At the time of the interview, almost 1 out of every two patients had already been hospitalized over 5 days ($f = 48.7\%$). Of the rest, 17.1% had been in the hospital 3-4 days, 11.8% for 2-3 days, 14.5% for 1-2 days and 7.9% were...
admitted that same day. Regarding visitors, 46.8% spent more than 8 hours next to their loved one, 30.6% stayed 4-8 hours in the patient room, 17.7% for 2-4 hours and 4.8% for less than 2 hours.

The comparative overall architectural and ambience evaluation, is shown in figure 1. Figure 1a shows categorical questions and figure 1b shows dichotomous questions. Further research questions studied are shown in figure 2 and table 3.

2.2.1. User group evaluation differences

Patients and visitors had significantly different interest to watch the view outside the window, $X^2 (2, N = 138) = 11.58, p < .01, \Phi_{Cramer} = .29$. Patients were less engaged, since they had moderate interest ($f = 38.2\%$) more often than visitors ($f = 27.4\%$) and reported complete lack thereof almost four times more often ($f = 22.4\%$ and $f = 6.5\%$ respectively). Patients were also less likely than visitors to evaluate the view outside the window as “calming” ($f = 82.7\%$ and $f = 96.8\%$), $X^2 (1, N = 138) = 6.92, p < .05, \Phi = .29$. The classification of the view as “pleasant” vs “unpleasant”, was also found to be different among the two user groups, $X^2 (1, N = 138) = 6.09, p < .05, \Phi = .21$. Whereas visitors gave positive feedback in their total, a few patients would assess it negatively ($f = 9.3\%$). With regard to daylight, patients experienced discomfort more frequently ($f = 38.2\%$) than visitors ($f = 19.4\%$), $X^2 (1, N = 138) = 5.78, p < .05, \Phi_{Cramer} = .20$.

2.2.2. Daylight evaluation impact

Patients that evaluated daylight positively were more likely to believe the window connected them to nature ($f = 68\%$), while those that felt indifferent were more likely to respond negatively ($f = 75\%$), $X^2 (1, N = 76) = 10.05, p < .01, \Phi = .30$. A significant interrelationship was also found with the view classification as “interesting” vs “uninteresting”, $X^2 (1, N = 76) = 7.97, p < .01, \Phi = .32$, since patients satisfied with daylight were more likely to give a positive view feedback ($f = 70.6\%$). When asked if they considered that watching a nice view was a positive feature of their window (w.p.f.), patients with good daylight impression were more likely to respond positively ($f = 96.4\%$), as opposed to those indifferent towards daylight ($f = 75\%$), $X^2 (1, N = 76) = 8.09, p < .05, \Phi = .32$. Moreover, patients were significantly influenced in assessing the ease of access to the view outside the window, $X^2 (1, N = 76) = 6.50, p < .05, \Phi_{Cramer} = .29$. The analysis showed that patients with positive daylight assessment tended to feel they could see easier ($f = 69.6\%$) than those with indifferent daylight impression ($f = 60\%$), in which case they were more likely to experience some degree of impediment ($f = 45\%$) than evaluate watching the view unobstructed ($f = 17.9\%$). Similarly, patients had a better chance to be interested to watch the view if they had a positive daylight impression ($f = 46.4\%$). When they reported indifferent daylight experience ($f = 20\%$), the likelihood of being accordingly neutral towards watching outside the window ($f = 40\%$) than feeling engaged ($f = 16.1\%$), $X^2 (4, N = 76) = 6.40, p < .05, \Phi_{Cramer} = .29$. Finally, a significant relationship was found with sunlight evaluation, $X^2 (2, N = 76) = 5.64, p < .05, \Phi_{Cramer} = .27$. Patients with positive daylight impression tended to assess sunlight positively ($f = 64.3\%$) considerably more frequently than indifferently ($f = 35.7\%$). In the case of neutral daylight impression, they were more likely to assess sunlight accordingly ($f = 55\%$).
Table 3. Interrelationships found among the three research questions and their level of significance, according to the chi-square tests for both user groups. Dichotomous questions are marked with asterisk (*). Legend: \( P = \) patients and \( V = \) Visitors.

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<th>parameters</th>
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<th>daylight discomfort</th>
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Visitors were influenced by daylight assessment in evaluating shading, \( X^2 (4, N = 62) = 15.05, p < .01, \Phi_{Cramer} = .34 \), as well as sunlight \( X^2 (2, N = 62) = 10.48, p < .01, \Phi_{Cramer} = .41 \). Regarding shading, positive daylight impression was correlated with positive shading assessment more often (\( f = 74.5\% \)) than indifferent (\( f = 57.1\% \)). This group was also far more likely to feel the sunlight was nice, if daylight evaluation was positive (\( f = 74.5\% \)), as opposed to indifferent (\( f = 25.5\% \)). In the latter case, sunlight was first appraised neutrally (\( f = 71.4\% \)) and then positively.
2.2.3. Daylight discomfort impact

When asked if the watching a nice view is a positive feature of the window (w.p.f.), patients were more likely to respond affirmatively if they felt no daylight discomfort (f = 97.7%), as opposed to the case where they experienced nuisance (f = 79.3%), X² (1, N = 76) = 7.38, p < .05, Φ = -.3. Similarly, patients that reported no visual discomfort assessed the view as “interesting” more frequently (f = 72.3%) than those annoyed (f = 42.9%), X² (1, N = 76) = 5.43, p < .05, Φcramér = -.29.

Visitors were influenced by visual discomfort in considering that their window allowed excessive sunlight to penetrate the room, X² (1, N = 62) = 7.14, p < .05, Φ = -.3, because discomfort was associated with considerably higher probability to respond positively (f = 58.3%) than comfort (f = 20%).

2.3. Discussion

2.3.1. User group evaluation differences

Patient and visitor evaluations were moderately different (table 3), which is an inference that these user groups do not experience this physical setting all that differently. This would mean that visitors are also subjected to a considerable degree of stress, verifying the need to address and include them in relevant studies (Zimring, Reizenstein, & Michelson, 1987). Indeed, with regard to Greek practice, “visitors” are in effect round-the-clock caretakers, because nursing personnel is understaffed and patient family members actively participate in the care of their relative. This builds up to the inherent stress of having to visit a family member in a clinical environment. In that sense, the needs and expectations of patient and visitors have more common ground than we think.

Being in the hospital can be a major stressor by nature. If factors such as having to adjust to unfamiliar physical settings, compromise with lack of personal space or control and make efforts to cope with physical disability are collectively weighed in, patients are undisputably much more sensitive. This notion is consistent with statistical analysis findings. Patients had considerably less interest to see outside the window and felt the view was “stressful” or “unpleasant” more often than visitors. The reason seems to be the more frequent report of visual discomfort: Patients have limited physical mobility and adaptation capability. They are generally unable to move and adjust their body position, or control their environment, but also their view angle, which in some cases may coincide with solar angles (images 2b and 2c). The inability to address visual discomfort would probably result in stress (e.g. Evans & Cohen, 1987; Topf, 1994), which could entail adverse effects, like disinterest and poor evaluations of the view.

2.3.2. Daylight evaluation impact

Daylight evaluation was associated with view evaluation and the adjunct degree of engagement (table 3), in accordance to the natural interrelationship between daylight and view.

Patients with good daylight impression were more likely to feel that “connection to nature” and a “nice view” were within the positive features of the window of their room. They appeared engaged, were able to watch the view unimpededly and assessed it as “interesting” more frequently if they had evaluated daylight positively. These findings are broadly consistent with the positive correlation between sunshine and general predisposition (e.g. Walch et al, 2005; Beute & de Kort, 2013). Finally, the interrelationship of daylight and sunlight impression suggests a consistency in subjective holistic evaluation. The documented difference in the level of significance among patients and visitors could be explained by the different seating positions: With regard to the window, patients were seated sideways, which is generally encouraged in day-lit spaces. Visitors were mostly seated facing it, which could facilitate glare and general visual discomfort conditions.

A final, more general difference between the two user groups is ubiquitous when regarding the extent of daylight evaluation impact, as well as of the environmental parameters related to it. Daylight is a major contributor to the patients’ overall state of health and mood and it is therefore expected to affect them more than other occupants (e.g. Dijkstra et. al., 2006, Beauchemin & Hays, 1998, Walch et. al., 2005). Similarly, view is of fundamental importance and related research has proven its influence on patient health and wellbeing (e.g. Ulrich, 2008). Consequently, it is logical that the evaluation of these two environmental attributes would feature a considerable overlap. On the other hand, visitors were also influenced by daylight, but this dynamic extended to more predicted relationships.
2.3.3. Daylight discomfort impact

Contrary to architectural documentation, most of the participants did not report discomfort, further verifying that subjective and objective evaluations may deviate from each other (e.g. Meir et al, 2009) and need to be equally considered (Wang & Boubekri, 2011).

Patients partially associated daylight discomfort with view assessment, i.e. its quality as “interesting” as well as its role as a positive window feature, further enhancing the rationale elaborated in previous sections (figure 2). Accordingly, visitors were confirmed to experience less influence by visual discomfort and only to the extent that excessive sunlight penetration was considered a negative window feature, which could be further explained by their seating position.

3. Experimental study

3.1. Overview

This study evolves around the architectural research design of a strategy corresponding to the urgent shading need, while safeguarding the proven therapeutic qualities of sunlight and view. Since the effectiveness of any solution depends considerably from the end user of the space in question, findings from the statistical study of the survey would be used as general guidelines.

| Table 2. Regional geographic and climatic data of Athens (Technical Chamber of Greece, 2010) |
|-----------------------------------------------|-----------------------------------------------|
| Latitude                                      | Outdoor Av. Temperature (°C)                  |
| March                                         | June                                          |
| 37° 54’                                      | 12,3                                         |
| June                                          | 25,4                                         |
| December                                      | 12                                           |
| Longitude                                     | Monthly Average Clear Sky Coefficient         |
| March                                         | June                                         |
| 23° 43’                                      | 0,48                                         |
| June                                          | 0,62                                         |
| December                                      | 0,44                                         |
| Altitude (m)                                  | Average Sunny hours/day (hrs)                 |
| March                                         | June                                         |
| 15                                            | 6                                            |
| June                                          | 11,4                                         |
| December                                      | 4,4                                          |

3.2. Instruments and procedure

By studying climatic conditions (table 2) and overlaying solar altitude and azimuth angles on the floor layout and section drawings, the direct annual sunlight penetration conditions were ascertained (image 2c), further documenting previous findings (Sklavou and Tzouvakis, 2015a). Nevertheless, shading in patient rooms can be proven a challenging task, because the equally important needs for solar shading, daylighting and view may contradict one another. An integrated shading strategy would ideally consist of two parts; an external that would block excessive sunlight before entering the space and an internal that would mainly address visual comfort issues. This study focused on the external shading device and specifically ways to enhance the shading provided by the balcony. In this way, the magnitude of adverse solar conditions needed to be handled internally would be even lower.

Sustainable architecture principles, EBD suggestions and survey findings guided the architectural research. One intuitive survey finding, consistent with literature suggestions, was that daylight had indeed a positive relationship with occupants of the patient room. Moreover patients were affected by discomfort significantly more than visitors and this had an impact especially on their predisposition towards the view. Therefore the design should try to balance the need for shading with that of enhancing the restorative qualities of daylight and view.
The existing south patient rooms were used as case studies to conceptualize the architectural design and investigate solar geometry issues and view facilitation. The resulting configuration was assigned on daylight and energy simulation models of the existing situation to investigate the relevant footprint.

The design was an external shading device, comprising elongated shading slats, carried by a steel frame structure fixed on the balcony slabs. The slats extended horizontally downwards, shading the space beneath. Choosing between a dynamic or static system is a multivariate decision that extended beyond the scope of this study. In order to provide useful inferences for both cases, two instances were investigated (Image 4). The first instance corresponded to a medium state of shading, where enough space was left for completely unobstructed view. Four external shading slats extended two meters (2m) below the balcony slab, leaving enough space for unimpeded view. At the same time, this design reduced the visible sky angle from 50° to 4°. The second instance employed three more slats to cover the extent of the floor height. But for the space between the slats, no visible sky view was featured. Finally, the slat angle chosen, i.e. 45°, was ascertained to effectively address critical solar angles.

The scenarios tested were organized as follows: the base case scenario ("as built") described the existing situation. Scenario (A) addressed the application of material suggested visual properties. Scenarios (B) and (C) discussed the medium and full shade case respectively (Image 4).

Two room versions were studied, corresponding to the side that the patient beds were actually located, with respect to the layout i.e. the “right” and the “left”. Regarding daylight simulations, two points of interest (POIs) addressed the patient bed head close to the window and the one in the back of the room, generating four POIs in total: the right front (“RF”), the right back (“RB”), the left front (“LF”) and the left back (“LB”) (Image 2a). Curtains were assumed to be drawn open, since this was documented as their most common state (image 3a, 3c and 3d). Each bed was assigned a daylight sensor, which functioned as a proxy for the patient head. Apart from documenting daylight illuminance per sensor on each POI E(lux) and the maximum probability for discomfort glare to appear (sDGPmax) (Wienhold & Christoffsen, 2006), each simulation ascertained the percentage of annual daytime hours that illuminance was above the set point of $E = 300$ lux (Daylight Autonomy – DA), the time that the set point criteria (as well as a certain illuminance range above and below) was met for a reasonable timeframe (continuous daylight autonomy – conDA), and the percentage of annual daytime hours that illuminance levels extended within a useful range, i.e. $100 \text{ lux} \leq E \leq 2.000 \text{ lux}$ (Useful Daylight Illuminance – UDI) (Reinhart et al, 2006).

With respect to energy simulations, only one model was studied, since both rooms shared the same thermal properties. Each scenario was evaluated on energy (kWh) and financial (€) resource usage in order for the
thermostat, assigned inside the thermal zone, to meet national regulations (Hellenic Ministry of Economy and Hellenic Ministry for the Environment, 2010).

Simulations were performed in NREL’s OpenStudio (e.g. Guglielmetti, Macumber and Long, 2011) using Radiance for daylight documentation and EnergyPlus for energy assessment. Material properties, equipment and loads were configured according to international suggestions (ASHRAE, 2009) and national specifications (Hellenic Ministry of Economy and Hellenic Ministry for the Environment, 2010). Summer and winter solstice were chosen to present daylight data, whereas energy and financial resources were calculated for winter months December, January and February and summer months June, July and August. Correlation of energy units to currency was done according to the tariff effective in this hospital.

3.3. Results

Daylight results, i.e. dynamic daylight metrics, illuminance and maximum daylight glare probability, are shown in figures 3, 4 and 5 respectively. Resource consumption is shown in figure 6.

3.3.1. Base case scenario – “as built”

These south facing patient rooms receive abundant natural light, leading to high autonomy (DA = 0.83 and conDA = 0.86) but low useful range (UDI = 0.64). The front POIs are subjected to stronger light (ERF = 19136.59 lux and ELF = 18800 lux), which, during winter, can be three times higher than the back POIs (ERB = 5929.74 lux and ELB = 5882.07 lux). Accordingly, the probability of glare is evident and two times higher in the front (sDGPRF = 2.62 and sDGPF = 2.62) than the back (sDGPRB = 1.19 and sDGPLB = 1.16). Summertime featured significantly lower daylight metrics. Regarding resource used, heating energy required was 997.85 kWh and cooling was 2096.39 kWh, (figure 6), which translated to 54.16 € and 123.06 € respectively.

![Figure 3. Dynamic Daylight Metrics (DA: Daylight Autonomy, conDA: continuous Daylight Autonomy, UDI: Useful Daylight Illuminance) calculated for all POIs (LB: Left Back, LF: Left Front, RB: Right Back and RF: Right Front) and scenarios tested (“as built” and scenarios A, B and C).](image-url)
Figure 4. Illuminance E (lux) calculated for all POIs (LB: Left Back, LF: Left Front, RB: Right Back and RF: Right Front) and scenarios tested tested (“as built” and scenarios A, B and C), at summer and winter solstice noon.

3.3.2. Scenario A.

Illuminance levels were elevated, which was especially conspicuous at the back of the room; during summertime this increase was more than 30%, \(E_{RB} = 1421.46 \text{ lux} \) and \(E_{LB} = 1476.82 \text{ lux}\) and during winter it was considerably less, i.e. approximately 10%, \(E_{RF} = 19701.36 \text{ lux} \) and \(E_{LB} = 6568.58 \text{ lux}\). The front of the room was not significantly affected and the increase corresponded to roughly 5%. There was a consequent mild impact on autonomy \((DA = 0.84 \text{ and } \text{conDA} = 0.87)\). Although glare probability remain unchanged, the increase of overall illuminance affected the useful range of illuminance \((UDI = 0.6)\), lowering it by 5 – 8%.

3.3.3. Scenario B.

Illuminance levels were reduced considerably throughout the room. During winter solstice, this was collectively higher in the front \((E_{RF} = 9540.16 \text{ lux} \text{ and } E_{LF} = 9667.94 \text{ lux})\) than the back \((E_{RB} = 4475.74 \text{ lux} \text{ and } E_{LB} = 6567.94 \text{ lux})\). This translated to a rate of 50% decrease of daylight for all POIs notwithstanding POI \(RB\), where the reduction rate was almost 35%. Glare probability was accordingly scaled down, i.e. 40% in all POIs \((sDGP_{RF} = 1.52, sDGP_{LF} = 1.50 \text{ and } sDGP_{LB} = 0.67)\), notwithstanding RB, where the decrease was 20\% \((sDGP_{RB} = 0.88)\). This effect was also noted during summer solstice. Illuminance was reduced more than 40\% near the window \((E_{RF} = 1110.42 \text{ lux} \text{ and } E_{LF} = 1322.48 \text{ lux})\), as well as the POI \(LB\) \((E_{LB} = 833.02 \text{ lux} \text{ and } E_{LB} = 1004.05 \text{ lux})\). Glare probability reduction was measured at 27\% close to the window \((sDGP_{RF} = 0.40 \text{ and } sDGP_{LF} = 0.30)\), 20\% at the POI \(RB\) \((sDGP_{RB} = 0.31)\) and 11\% at the POI \(RB\) \((sDGP_{LB} = 0.34)\). Among the dynamic daylight metrics, UDI was influenced the most, since an overall growth of 18 - 20\% was noted on all POIs with the exception of the POI \(RB\), where the corresponding increase rate was 15\%. Accordingly, other dynamic daylight metrics decreased more in the front \((DA_{RF} = 0.79, DA_{LF} = 0.81 \text{ and } \text{conDA}_{RF} = 0.85, \text{conDA}_{LF} = 0.85)\) than the back \((DA_{RB} = 0.83, DA_{LB} = 0.81 \text{ and } \text{conDA}_{RB} = 0.85, \text{conDA}_{LB} = 0.85)\).

Regarding energy, this configuration reduced cooling resources by 3.5\% \((2023.89 \text{ kWh and 118.77 €})\), but at the same time raised heating demand by 16.5\% \((1163.36 \text{ kWh and 63.59 €})\).
3.3.4. Scenario C.

With regard to the unshaded state, the reduction rate during winter was calculated at more than 60% in all POIs ($E_{RF} = 7372.40$ lux, $E_{LF} = 7095.70$ lux and $E_{LB} = 2452.21$ lux) except for POI_{RB}, which was 45% ($E_{RF} = 991.20$ lux). Consequently, glare probability was more than two times lower in the front POIs ($sDGP_{RF} = 1.15$, $sDGP_{LF} = 1.13$ and $sDGP_{LB} = 0.55$) notwithstanding POI_{RB}, where the likelihood was almost 45% lower ($sDGP_{RB} = 0.68$). Likewise, sunlight penetration during summer was also mitigated. Illuminance reduction in proximity to the window was 56% on the right side ($E_{RF} = 991.20$ lux) and almost 60% on the left ($E_{LF} = 961.18$ lux). Further away this decrease accounted for 45% on the right ($E_{RB} = 769.60$ lux) and 56% on the left ($E_{LB} = 638.71$ lux). Accordingly, the probability of an occupant experiencing glare was lower by 37% near the window ($sDGP_{RF} = 0.35$ and $sDGP_{LF} = 0.35$), 30% at the left back ($sDGP_{LB} = 0.28$) and 22% at the right back ($sDGP_{RB} = 0.30$). In effect, UDI was increased by 20% in all POIs, while autonomy was lowered by approximately 3-4%. Compared to Scenario B, illuminance and glare probability were reduced approximately by 20%. Regarding dynamic daylight metrics, autonomy was not significantly affected (approximately 1% decrease) and UDI was increased by 4% to 6%.

This scenario demanded 1962.56 kWh and 115.17 €, for cooling, which translated to 6.4% less energy and financial resources for cooling compared to the unshaded state and approximately 3% compared to Scenario A. Nevertheless, with regard to heating and compared to the unshaded state, resource consumption would rise by 21.6%, i.e. 1213.5 kWh and 66.44 €, which would account for 4.3% increase from Scenario A.

3.4. Discussion

Architectural documentation demonstrated that the abundance of sunlight throughout the year would most likely facilitate discomfort situations (Sklavou and Tzouvakas, 2015a). Daylight simulation verified this finding and ascertained wintertime as associated with significantly higher illuminance levels, which in turn resulted in high autonomy indices, but also higher glare probability and low UDIs. That was more conspicuous in the front than the back of the room, which is consistent with building physics and literature (e.g. Ito, Yuming, Watanabe and Tanabe, 2008).
Assigning the suggested material visual properties, visual discomfort conditions became even more acute, since the test case remain unshaded. This was not surprising, since this modification entailed raising wall and ceiling reflectance, without adjusting the high glazing visible transmittance \( T_{\text{vis}} = 0.80 \) respectively. However, frequent re-coloring is generally advised in healthcare settings, so this scenario could serve as a generic base case where alternate strategies could be compared to.

The external shading system proposed served mainly as a measure against summer overheating, which is critical in Mediterranean climates (e.g. Hellenic Ministry of Economy and Hellenic Ministry for the Environment, 2010). Nonetheless, along with unwanted sunlight, shading strategies also block a considerable amount of daylight, whereas visual comfort solutions during winter may also have an undesired effect on sunlight.

Indeed, the shading configuration investigated, mitigated the cooling energy required to reach the cooling set-point by 3.5% for Scenario B and 6.4% for Scenario C. This may not come across as a significant reduction, but concerning rational resource use in hospitals, even the smallest amount saved can be relocated elsewhere. Regarding daylight, overall visual conditions were improved; illuminance and glare probability were significantly reduced, with an overall positive impact on dynamic daylight metrics, too. Of course the impact on the POI\(_{RB}\) was not as conspicuous, mainly because of the pre-existing interrelation with solar geometry; notwithstanding the ample daylight throughout the room, illuminance away from the window is considerably lower than that close to it, which is consistent with building physics. In addition, the right side was also subjected to the reflected light on the left wall (image 1b): The back POI has a bedscape which includes much bigger wall surface and therefore experiences a lesser decrease in daylight metrics. Regarding winter, the effect of both shading configurations on the daylighting of the patient room was much more intense. Scenario B blocked low winter sunlight and confined the visible sky angle, resulting in illuminance being decreased by half, notwithstanding POI\(_{RB}\), for the reasons mentioned above. Collectively, data suggested the visual environment was even more comfortable. Scenario C had an even greater impact.

Unfortunately, there was a predicted significant increase in resource consumption to meet the heating set point. This translated in considerably more energy and financial cost in Scenario B and even more in Scenario C. This suggests that a static system comprising any of the configurations tested should be avoided. However, between the two shading options, scenario B would be the better than C. On the other hand, if the shading configurations tested
were construed as instances of a dynamic shading system, the potential towards a sustainable healing environment becomes conspicuous. Of course, the impact on electric lighting demand and the corresponding electric energy consumption could be significant, so a complementary study could yield valuable information.

4. General discussion - Conclusions

This paper comprised a field study investigating user perception of a Greek patient room visual environment within the particular climatic and cultural conditions and an experimental study that leveraged these findings towards sustainable evidence based design solutions. Among the key findings of the field study was that occupants of patient rooms, particularly patients, are indeed greatly affected by daylight on their perception of their visual surroundings. Combining solar geometry study, overall survey findings and simulation results, an intuitive judgement was made that all patient room occupants, especially patients, adapted to a higher intolerance threshold, to enjoy the merits of sunshine and view.

Following these inferences, two versions of an external shading system were conceptualized and tested. Evaluated exclusively on their outcomes, they would be rejected, based on the damages calculated. Nonetheless, these were two specific instances designed with the primary objective of effectiveness during specific adverse conditions. Other studies which could include equinoxes, local critical times, alternate window configurations, as well as building typologies could produce other interesting options. Complementary lighting studies and the corresponding electric energy consumption comparative studies could offer valuable information towards a comprehensive holistic evaluation. The possibility of this system to be dynamic and handled by the building management system (BEMS) should be considered as well. Although this entails aggregated first cost and its fiscal long-term advantage should be carefully evaluated, experience and literature underline that regarding hospitals, construction costs are only a fraction of the operational and the maintenance costs (e.g. Pützep). Design solutions within this frame of thinking could contribute to rational use of energy and financial resources. If the inherent bond between humans and nature is considered (Wilson, 1984) and the effect of sunshine on overall patient outcomes is factored in (e.g. Beauchemin & Hays, 1998; Dijkstra et al., 2006; Walch et al., 2005), then architectural EBD solutions that seem fiscally disadvantageous at first are put in a different perspective.

Architects need to acquire an active role and a multidisciplinary approach of healthcare architecture. The primary objective of creating a healing and restorative environment that will help ease the pain and stress of the patients seems to have a conditioned positive effect in the rational use of energy and overall resources. More architectural research has to address the multi-leveled relationship. It is becoming abundantly clear that merely quantitative and objective measures provide only the frame of reference to understand subjective issues. Studying user perception and conducting thorough post occupancy evaluations (POEs) could be proven valuable. Furthermore, because the physical environment is adjunct to its climate, terrain and culture, future work should take such particularities, similarities and differences into consideration.

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