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Objective and subjective criteria for assessing the light environment in vessel spaces: Application and comparison

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ABSTRACT

Fatigue is a major factor in human error, which in turn affects maritime accident rates. For this reason, conditions in the light environment present in the ship?s work and rest areas can play a role in causing fatigue among crewmembers. This paper assesses conditions in the light environment within the spaces of a roll-on roll- off vessel. Objective factors, measured over a two-year period at sea during the vessel?s operation, are contrasted with subjective aspects, reflected in surveys about the ship?s environment. Moreover, this article compares the results of this assessment with the implementing regulations for professional activity on land is similar to the on-board work examined here.

1. Introduction

Great progress has been made in risk prevention in all the productive sectors. Nevertheless, in shipping, there are areas that are still in need of specific regulation. One of these has to do with the lighting found in the zones where crewmembers work and rest (Iradi-Mateo G., 2011).

Vessels are unique in that they serve as both the workplace and residence for the crewmembers. Therefore, one must take into account the external environmental conditions affecting the areas in which the work is carried out as well as the conditions inside (Bridger et al, 2011). When it come to vessels, it is thus difficult to distinguish between what the crewmembers are exposed to in their living and work areas (Mc Namara et al., 2000).

Fatigue is considered a major cause of human error (Shea, I. P., Grady, N., 1998; Lützhöft et al., 2007; Akftar and Utne, 2014; Havold, 2015; Bal et al, 2015b). In an effort to reduce this risk on vessels, maritime industries have developed a wide range of norms that delimit the hours of work and rest. For example, since 1990, the International Maritime Organization (IMO) has adopted a series of resolutions on fatigue and ways to mitigate it (Bal et al., 2015to; ILO, 2002).

The lighting of crew spaces should facilitate visual task performance and the movement of crew members within a space. Visibility is a fundamental factor in optimising task performance. (ABS, 2016). Ineffective lighting systems contribute to eye fatigue, a rise in human error and accident rates, and increases in reaction/response times. (Hendrick, 1999; Sanders and McCormick, 1993).

However fatigue is a complex phenomenon (Akftar and Utne, 2014; Zhao et al., 2011) that can have various physical and psychological causes (Bal Et al. 2015a). These can be divided into four main categories: some are specific to crewmembers, others are related to administrative matters; the third group has to do with the vessel and the fourth, with the environment (Table 1). As seen in this diagram, deficiencies in the light environment are linked to ship-specific factors. Lighting conditions are influenced by ship design and automation, as well as comfort on board. Similarly, under the category, environmental conditions, the light environment will be included among other "interior factors" (Bal et al., 2015a).

Table 1. Factors causing fatigue among seafarers, grouped under four main categories. Source: Prepared by the authors, based on Bal et al., (2015a).

The category **Ship design and automation** refers to the fa-

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Table 1: Factors causing fatigue among seafarers, grouped under four main categories.

Specific to crewmembers	Administrative	Ship-specific	Environmental
Sleep condition			
Biological clock	Organisational structure		
Stress		Ship design and automation	Interior
Work load Personal	Ship organisation		Exterior
factors	Voyage planning	Ship comfort	

Source: Prepared by the authors, based on Bal et al., (2015a).

tigue that is due to unsuitable vessel design; this fatigue is experienced by crewmebers as they work. It is crucial to take ergonomics into account when designing work spaces, such as the control bridge (Bal and

Arslan, 2011), where machinery is located (in the engine control room ECR and engine room ER) and cargo holds (Lundh et al, 2011; Arslan and Er, 2008; Pomeroy, 1994). However, a paradox exists here. Advances have been made in supervising and controlling machines thanks to the mechanisation and automation of these processes. Moreover navigational devices facilitate bridge activity. However, these advances have also led to a reduction in staffing levels, which in turn means that each member faces a greater workload (Bal and Arslan, 2011; Havold, 2015).

A second category, **Ship comfort,** will play a major role in reducing fatigue (Xhelilaj and Lapa, 2010). It refers to how common spaces and accommodation are designed in terms of the thermal environment, noise, vibrations and lighting. In recent decades a global trend has been to build increasingly big and complex vessels that are fully automated (ILO, 2001; Stopford, 2009). Crew numbers are being reduced and these workers tend to come from around the world (Rodriguez-Martos, 2007; Bal and Arslan, 2011) While more and more space is devoted to cargo space, at the cost of living conditions, personal safety and other human considerations.

Among the environmental factors leading to fatigue, what goes on in the interior has to be looked at in terms of lighting, noise, vibrations and the ship's movements (Bal et al., 2015a).

2. Light environment.

Light is a basic human need; correct lighting, therefore, is essential for wellbeing and health. Given that 50 % of sensory information received is visual, lighting- an environmental feature- and vision – a personal one- must complement each other (Iradi- Mateo, 2009). Light can also create a certain atmosphere, provoke an emotional response or draw one's attention to something. As a result, circadian cycles can be altered, which may have a bearing on sleep-wakefulness cycle, variations in body temperature, the state of alert and neuroendocrine functioning through the secretion of cortisol and melatonin ("Resetting of the circadian clock by a conditioned stimulus", Nature, February 8, 1996).

It has been assumed that the human circadian clock was much less sensitive than that of other mammals. According to this idea, only sunlight or an artificial light of great intensity, between 7000 and 13000 (lx), could modify the human circadian cycles. However recent studies (Llaneza-Álvarez, 2007) have shown that low and moderately intense artificial light levels of around 180 (lx) can come to vary circadian rhythms in some way. On the vessel, both work and rest can take place in the day as well as at night. This means that the light environment has a huge impact on how well crew members do their jobs and rest. On the whole, wherever an activity is carried out, the lighting system has to fulfil the requirements included in (INSHT, (2006) and (Llaneza-Álvarez, 2007).

In photometry, lighting levels or luminance is measured in total luminous flux (in lumen, lm), using the lux (1 Lx= lm/m2), as this luminance occurs on a surface, per unit area. However, determining the luminance for a space is not a straightforward task. The recommended values, according to the task and surroundings, are based on subjective assessments made by the users, in terms of visual comfort, pleasant feelings and visual performance. As a standard user does not exist, people can have different impressions about the same installations (Iradi-Mateo, 2011).

2.1. Visual Comfort.

As for visual comfort as a general idea (Darwich-Soliva, and Fernandez-Dominguez, 2002; CEI, 1986) particular aspects must be taken into account when going from the initial concept to the design in vessel spaces:

1º *Luminance*, as natural lighting is definitely better than artificial versions, from the physiological point of view, due to its spectral composition. It is also more economic. On board the vessel, natural lighting is difficult to achieve and maintain because of the variables related to navigation, meteorological conditions and the interior distribution of spaces within the vessel. Its value is the function of glazed surface.

2º *Glare*, in those spaces of the vessel in which very shiny surfaces reflect the light coming in at eye level. Visual fatigue is produced when the individual constantly has to adjust his or her retina to two levels of lighting. This situation may arise with the shiny, polished surfaces of stainless steel found on the siding and galley work surfaces.

3º *Luminance equilibrium* is especially important wherever data visualisation displays are required, such as in the control bridge (Bal and Arslan, 2011) and engine control room (Lundh et al, 2011; Arslan and Er, 2008; Pomeroy, 1994).

4º *Light colour choice*, which will influence how dimensions are perceived and how the occupants feel. Although it is an important factor in all the spaces, it is especially so wherever manoeuvres are carried out, such as in cargo holds and the engine room.

5º General or space specific lighting may lead to *glaring*, which plays a role in the visibility on deck and in the control bridge to improve night-time navigation (Bal and Arslan, 2011).

6º *Light and luminaries types*; a distinction is made between industrial lighting for work spaces on the vessel and residential lighting for accommodation and leisure.

2.2. Legal and regulatory framework.

As is the case with other aspects of a vessel's design project, lighting across the various spaces for accommodation and work will be conditioned by regulations specific to each. Designers have to take into account the implementing regulations set by classification society (CS) chosen by the vessel owner, by the country of the vessel's flag and by international agreements (Carral et al., 2013).

The SC specifies some levels of minimum lighting required, so that crew members can effectively carry out their activities in the various vessel spaces. Another objective is to

avoid discomfort and prevent accidents. Table 2 presents the values given as acceptable minimums by the classification society, American Bureau of Shipping, (ABS, 2014) for the vessel spaces being studied.

Table 2- Objective criteria, general lighting levels for the spaces under study in accordance with ref. (ABS, 2014)

As for the regulations set by the flag's country on general space lighting, the European Committee of Normalisation (CEN) (CEN, 2012; CEN, 2012b) standard specifies design criteria for lighting in terms of quantity and quality: recommended luminance for work areas, glare shielding and limits in luminaries luminance. There are also norms that come from the country of the vessel's flag of the vessel on lighting levels for all the spaces (AENOR, 1985; AENOR, 1985), in accordance with the type of task to be carried out in the workplace. This is conditioned by how visually challenging a task is. All the regulations that are not specifically applied to vessels will be used to establish a reference for the objective criteria determined by (ABS, 2014) (Table 13)

On the other hand, given the nature of the work done in the control bridge and machine control room, the point of reference is (INSHT, 2006b) on workplaces with data visualization displays. Moreover, the technical guide (CEI, 1986) on using equipment with visualisation displays clarifies that: "most of the current visualization displays, with anti- reflective coating and greater range of contrast adjustment, make it possible to use 500 (lx) lighting, which is the minimum recommended level for common office work". "That is to be the case with positive polarity screens (characters or dark strokes on a light background). Nevertheless, as for screens with negative contrast images (light characters on a dark background), a lighting level of around the 300 (lx) is recommended".

Among **international agreements** affecting the accommodation on a vessel, another legislative framework for lighting can be found in the International Labour Organization (ILO) agreement on crew accommodation (ILO, 2006). Related ILO documents also specify general considerations for living spaces without providing specific parameters.

Carral et al (2013) was faced with a similar situation on examining the implementing regulations for on board equipment and spaces following the diagram proposed here. The study turned to the last major institution whose agreements are on an international scale: the IMO. However, it is striking that there are no IMO regulations on lighting for vessel.

3. Results obtained.

Over a period of two years, a longitudinal study was carried out on a roll on-roll off vessel under the Spanish flag. This study focused on the light environment in the different spaces where crew members carry out their work and personal life (Iradi-Mateo, 2011). In the first year all the cabins occupied by the crew and the cargo holds were examined, while in the winter and summer of the second year, the focus moved to the control bridge, Lounge- canteen for officers and crewmembers, engine control room, engine room and galley.

In all the cases these environments were assessed from three distinct approaches:

- Objectively, by analysing the indices and resultant parameters for the time measurements, in accordance with the CS regulations for this type of space and the activity carried out in it (table 2).
- Subjectively, with the crew responding to surveys on environmental conditions.
- Comparatively, with other land-based (as opposed to on-board) regulations applied to places in which similar work is being done.

3.1. On board focus of the study.

The vessel under study comprises an engine room, superstructure, accommodation and control bridge along the stern. This vessel is specially designed for transporting cars, trucks and heavy machinery. For loading and unloading goods, the roll-on/roll-off system is employed, making it easier to go directly from the vessel to the dock and vice versa. During the periods of study, the vessel followed routes along the North Sea shipping zones and off the north coast of Spain.

Table 2: Objective criteria, general lighting levels for the spaces under study in accordance with ref. (ABS, 2014).

SPACE	OBJECTIVE CRITERION (ABS, 2014) (lx)
Control bridge	300 day, 0-20 night
Cargo holds	200
Engine room	200
Control engine room	300
Lounge – canteen	300 canteen/ 150 Lounge
Cabins	150
Galley	500

Source: Authors.

3.2. Resources employed in the investigation.

3.2.1. Lux meter and software.

To measure the lighting, a PCE-174 lux meter was used. Its range fell between 400 (lx) and 400 (klx), in accordance with IEC 1010-1, IN 61010-1 and DIN 5031. For twenty minutes, the lux meter sensor was held perpendicularly to the main light focus and possible reflections were avoided (INSHT, 2006b). Specific programs for measuring equipment were employed: version 1.3 of the PCE Group Light Put for programming and collecting the lux meter data.

3.2.2. The data gathering process through surveys.

On the vessel, there were 26 crew members: Team A and Team B, who served as a back- up for the first group. Two questionnaires were distributed to each crewmember, one for winter and the other for summer. Their questions were based on (Sanz-Merinero and Sebastián-García, 2002) and on the L.E.S.T method, adapted to the particular conditions of a vessel. The researchers turned to the Analytical Method for Working Conditions created by F. Guélaud, M.N. Beauchesne, J. Gautrat And G. Roustang (Gueland Et al, 1977) members of the Laboratoire de Economie et Sociologie du Travail (L.A.S.T.), of the C.N.R.S., in Aix-in-Provence. With this method, recommended by (INSHT, 1987), it is possible to quantify and then measure variables that are frequently handled in a very subjective manner. Questions included:

1.- Would you say that, where they exist, windows and portholes are kept clean,?

2.- When lights burn out, do they go unchanged for longer than 24 hours?

3.- Are there any flashing lights?

4.- Are there any lighting that flickers?

5.- Are there any lighting that is blinding in its intensity?

6.- In the spaces where you spend longer periods of time, are there any reflections and/or shadows?

7.- In the spaces where you spend longer periods of time, are any windows located directly in front of you?

8.- With the lighting in this space, can you properly distinguish the colours of the objectss around you?

9.- For the tasks you normally carry out, are the objects that you see located inside the horizontal plane (with frontal vision, 35º to the right and 35º to the left), and/or inside the vertical plane (with frontal vision, 15º upwards and 45º downwards)?

10.- Do you feel there is a sharp contrast between the lighting in the work zone and the one used in the surroundings that fall within your range of vision?

11.- Do you feel that the lighting level in this space is suitable for the task you normally have to carry out?

12.- Have you ever experienced discomfort, like tired sight or itchiness in your eyes, due to the lighting?

13.- Could the existing lighting for the work areas be described as “safe” and the one in the areas for resting as “comfortable”?

14.- In both spaces, would you prefer more natural sunlight?

15.- Would you prefer to be able to adjust the level of artificial lighting according to your liking?

The answers have been evaluated and marked according to Table 3:

3.3. Description of the spaces being assessed and positioning of the measuring equipment.

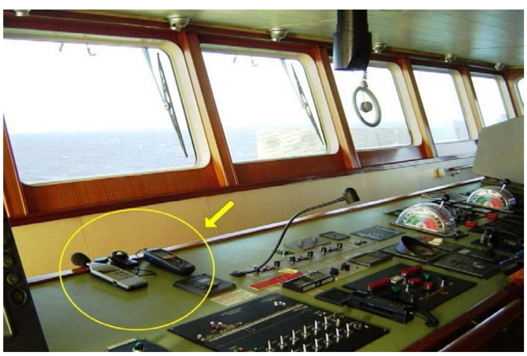
Figures 1, 2, 3, 4, 5 and 6 describe the vessel spaces that have been studied in terms of dimensions and levels of occupation, as well as the positioning of the measuring equipment and the existing lighting devices.

Table 3: Evaluation of the answers to light environment questions.

Response	Never (100% no)	almost never (75% no)	sometimes (50% yes,50% no)	almost always (75% yes)	always (100% yes)
Score	0	1	2	3	4

Source: Authors.

Figure 1: The control bridge has these dimensions: 16.5 x 8.5 x 2.10 (m). The level of occupation of the bridge is two people during navigation. Natural light, through portholes and windows. Artificial light: general type, two recessed 18 (W) fluorescent tubes behind a screen with a neutral daylight tone, colour rendering index (CRI) of 80 and correlated colour temperature of (CCT) 4000 K.



Source: Authors.

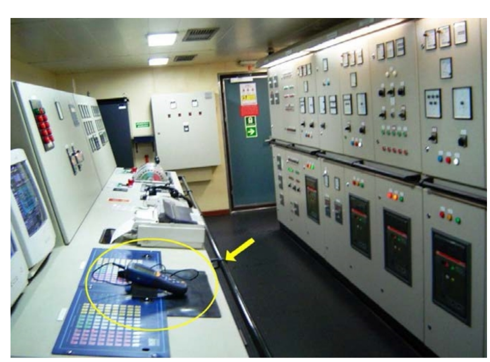
Figure 2: Cargo holds. Loading space of load made up of seven cargo holds, without transversal divisions and interconnected by means of fixed and mobile ramps made of uncoated steel. During unloading and loading, the level of occupation in cellars can vary of between 30 and 40 dockworkers and crew. Generic artificial lighting, by means of two 36 (W), fluorescent tubes (cold daylight tone) in weatherproof fittings with a colour rendering index (CRI) of 80 and correlated colour temperature (CCT) 6500 K.

Source: Authors.

Figure 3: Lux meter in the engine rooms consisting of two non-compartmentalised decks. In deck number 1, the dimensions were 30 x 20 x 2 (m) and, in number 2 the dimensions were 40 x 20 x 3 (m). Generic artificial lighting, 2 36 (W) fluorescent tubes bulbs (cold daylight tone) in a weatherproof fitting, with a colour rendering index (CRI) of 80 and correlated colour temperature (CCT) of 6500 K.

Source: Authors.

Figure 4: Lux meter in the engine control room, whose dimensions are 11 x 4 x 2.10 (m). One or two people usually occupy this space. Artificial general type, by means of recessed screens with two 18 (W) fluorescent tubes bulbs (neutral day light), a colour rendering index (CRI) of 80 and correlated colour temperature (CCT) of 4000 K.

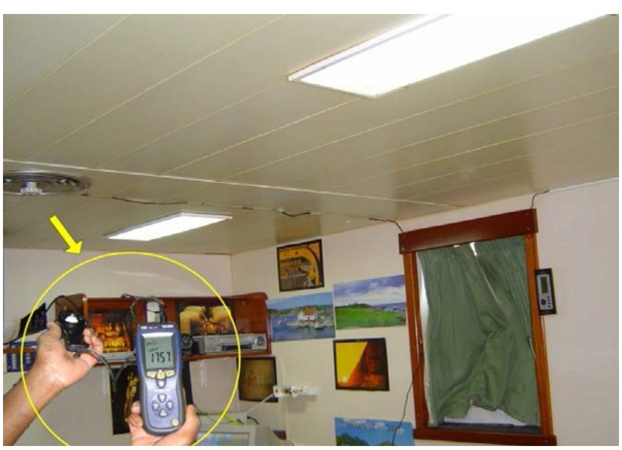


Source: Authors.

Figure 5: Lux meter in the galley, whose dimensions are 7.5 x 5.5 x 2.10 (m). This space is occupied by a single person during, at least 12 hours a day. Natural light, through portholes, and generic artificial lighting, by means of recessed screens holding two 18 (W) fluorescent tubes of (neutral daylight tone), with colour rendering index (CRI) of 80 and correlated colour temperature (CCT) 4000 K.

Source: Authors.

Figure 6: The cabins are located in the 8th deck; they all have the same dimensions: 5 x 3.5 x 2.10 (m). The average occupation per person is one/ 8 hours. The Lounge-canteen occupies a space of 7.5 x 6 x 2.10 (m) The time and level at which it is occupied varies throughout the day (between five and ten hours and with one to six people). Both, natural lighting, through a porthole and generic artificial lighting, by means of recessed screens holding two 18 (W) fluorescent tubes (neutral daylight tone), with a colour rendering index (CRI) of 80 and correlated colour temperature (CCT) of 4000 K.



Source: Authors.

4. Results of the lighting conditions.

4.1. Objective results (derived from the measurements taken).

Measurements (Tables 4 to the 9) were taken over several days in accordance with how the vessel was operating: sailing or during port operations, along several days, in different exterior lighting conditions and at different hours of the day. Each measurement took 20 minutes over four-minute intervals. The final results of the measurement were taken as the average value for all the intervals (Iradi-Mateo, 2009).

4.2. Subjective results derived from the surveys carried out.

In the second year two questionnaires were distributed to each crewmember (one to cover winter and another one for summer). There were 26 people on the crew: Team A and Team B, who took over from the others. Both stayed on board in roughly three-month intervals and the teams alternated twice a year. The results have been collected in Tables 10, 11 and 12.

5. Analysis of the results for lighting conditions.

An analysis of the results for the objective and subjective aspects- from measurements and surveys, respectively- is provided in Table 13. Moreover, this table shows to what extent the regulations in (ABS, 2014) have been fulfilled. A comparison is made with the guidelines for similar workplaces on land (AENOR, 1984; AENOR, 1985; CEN, 2012a).

For some spaces, such as in the engine rooms and cargo holds, the differences between the objective measures obtained and the limit values specified in regulations under which the vessel was designed (ABS, 2014) can be explained. The criteria shown here are values that new vessels must follow. However in this study, the measurements were taken in 2008, while the vessel had been built in 2001. From a visual inspection on board and the survey results for questions 2 to 4, defects could be found "sometimes" and "almost always". As lighting is poorly maintained, one can expect a striking decrease in its performance. The same argument could apply to certain zones of the galley and engine room, where the presence of oil-produced steam is common.

A reduction in lighting performance takes place for two basic reasons. The first is a decrease in the lighting efficiency from the bulb itself. Accumulated dirt may be a second cause; the greater the level of pollutants there are in a given space, the worse this problem is. High temperatures may also come into play, diminishing lighting efficiency in an engine room. This heat may shorten the working life of bulbs or other fixture components that diminish so much the lighting performance, like the life expectancy of the lamps and of the other fixture components like ballasts or starters. These effects are more striking in an engine room and the cargo holds, where the exhaust gases of the cars and trucks accumulate during the loading and unloading process.

The CIE (CIE 1996; CIE 2003) confirms that: "During the life of a lighting installation, available light progressively decreases. The reduction rates are a function of environmental, operating and age conditions. Lighting design is only as good as its execution. Good operations and maintenance are necessary to keep the lighting systems working as designed through the years. Neglect, poorly-chosen replacements, and misunderstanding of systems can undo all the improvements of good lighting design".

Table 4: Results of the lighting measurements in the control bridge.

SPACE	Vessel operations	Exterior conditions	Time interval	Type of illumination (1)	Average value (lx)
control bridge	navigation	sunny	noon	natural	727
	navigation	sunny	afternoon	natural	412
	navigation	cloudy	noon	natural+artificial	556
	navigation	cloudy	afternoon	natural+artificial	423
	navigation	dark	night	none	5

(1) Lighting is turned off during night time navigation. The only light comes from bridge equipment.

Source: Authors.

Table 5: Results of lighting measurements in the cargo holds.

SPACE	Vessel operations	Outside conditions	Time interval	Type of lighting (1)	Average value (lx)
Cargo holds	navigate	sunny	24 hours	artificial	172
	loading or unloading	cloudy	24 hours	artificial	173[(2)]

(1) Lighting stay on 24 hours.
(2) Near the stern ramp, with the ramp open for loading or unloading: 1.95 klx

Source: Authors.

Table 6: Results of lighting measurements in the engine rooms.

SPACE	Vessel operations	Outside conditions	Time interval	Type of lighting (1)	Average value (lx)
Engine room deck 1	navigation	any	24 hours	artificial	113[(2)]
Engine room deck 2	navigation	sunny	24 hours	artificial	172[(3)]
Engine control room	navigation	sunny	24 hours	artificial	202

(1) Lighting stays on 24 hours.
(2) Measurements taken at the height of the main engines.
(3) Measurements taken at the height of the main engines. In the auxiliary engine zones, 160 lux lx.

Source: Authors.

Table 7: Results of lighting measurements in the galley.

SPACE	Vessel operations	External condition	Time interval	Lighting type(1)	Average value (lx)
galley	navigation	sunny	noon	natural+artificial	220
	navigation	cloudy	noon	natural+artificial	200
	navigation	sunny	afternoon	natural+artificial	220
	navigation	cloudy	afternoon	natural+artificial	200
	navigation	dark	night	artificial	200

(1) The lighting stays on 24 hours.

Source: Authors.

Table 8: Results of lighting measurements in the Lounges-canteen.

SPACE	Vessel operations	External condition	Time interval	Type of lighting (1)	Average value (lx)
Lounge-canteen	navigation	sunny	noon	natural+artificia	320(2)
	navigation	sunny	afternoon	natural+artificia	187(3)
	navigation	dark	night	artificial	187(3)

(1) The lighting stays on 24 hours.
(2) Canteen zone
(3) Lounge zone

Source: Authors.

Table 9: Results of lighting measurements in the cabins.

SPACE	**Vessel operations**	**Outside conditions**	**Time interval**	**Type of lighting (1)**	**Average value (lx)**
Cabin	navigation	cloudy	noon	natural+artificial	261
	navigation	sunny	noon	natural+artificial	264
	navigation	cloudy	afternoon	natural+artificial	252
	navigation	sunny	afternoon	natural+artificial	255
	loading or unloading	sunny	afternoon	natural+artificial	251
	navigation	dark	night	artificial	206
	loading or unloading	dark	night	artificial	211

Source: Authors.

Table 10: Statistical results for the answers to question numbers 1, 2, 3, 4 and 5.

SPACE	Question number - Average value				
	1	2	3	4	5
Control bridge	2	0	0.71	0	0.36
Cargo holds	-	2.61	2.94	2.33	0.18
Engine room	-	2.50	1.50	2.60	0.60
Engine control room	-	0	0.50	0	0.50
Lounge-canteen	1.86	0.36	0.57	0	0.29
Cabins	0.88	0.27	0.31	0	0.04
Galley	1.50	0.5	0.5	0.5	1.5

Source: Authors.

Table 11: Statistical results for the answers to the question numbers 6, 7, 8, 9 and 10.

SPACE	Question number - Average value				
	6	7	8	9	10
Control bridge	2.71	4	3.93	3.14	3.14
Cargo holds	2.35	-	3.33	1.33	1.33
Engine room	2.50	-	4	0.60	0.6
Engine control room	2.20	-	4	1,80	1.8
Lounge-canteen	2.71	2.13	4	3.21	3.21
Cabins	2.65	3.46	4	4	4
Galley	4	3	4	3	3

Source: Authors.

Table 12: Statistical results for the answers to questions 10, 11, 12, 13, 14 and 15.

SPACE	Question number - Average value				
	11	12	13	14	15
Control bridge	3.07	0.29	2.64	3.57	2.79
Cargo holds	0.72	0.39	0.83	3.39	3.22
Engine room	0.5	0	1.4	4	3.4
Engine control room	2.6	0	3	0.6	2.5
Lounge-canteen	1.5	0	0.86	3.57	3.5
Cabins	1.69	0	0.77	3.42	3.27
Galley	1	0	2.5	4	3

Source: Authors.

Another source (Philips 1995) states that 15 000 operating hours could be equivalent to two years of navigation. With the lighting fixtures on for 24 h under these conditions, the lighting efficiency of the lamps falls by 20 % to 30 %, depending of the type of lamp.

There are was to calculate the effects of dirt and dust accumulating in the light fittings, although if the light is supposed to be weatherproof, the bulb should not be affected in the first place. One mathematical model for depreciation is from Van Dusen (1997), IESNA (1993) and APLE TR8 (1977). These studies deal with roadway lighting. However, dirt accumulates on the road in a similar way it does in specific spaces, like engine rooms and cargo holds. All these studies use the concepts of Lamp Lumen Depreciation (LLD), Luminaire Dirt Depreciation (LDD) and Luminaire Component Depreciation (LCD). In these, equations are determined with which curves can be drawn for each type of lamp and according to the level of pollution present. With similar results, these models predict that, for a three-year operating period, losses caused by surface pollution in the luminaire would be between 20% (low pollution $<150\ \mu/\text{m}^3$) and 55% (high pollution $> 600\mu/m^3$) .

With the combined effects of the lamp getting older and of dirt getting into the luminaire, lighting levels can be reduced by 44 % to 60 % when compared with the levels for the original design.

With this analysis of on board spaces, it can be generally concluded that the vessel's operating conditions while navigation or the loading and unloading process takes place, does not affect the average value obtained in the measurements. However outside conditions (whether it is sunny or cloudy) mean a variation of 20 lx - 30 lx in the measurement. Tables 13 and 14 provide the results obtained for vessel spaces.

Table 13. Comparisons of whether rules and/or recommendations for the light environment have been met in different vessel spaces.

Conclusions.

At the time measurements were taken, the vessel had already entered its seventh year of service. 57 % of the regulations were unfulfilled in four spaces: cargo holds, engine room, galley and engine control room. In areas where the levels of incompliance were high, the presence gases and dust pollution were keenly felt. These factors reduce lighting efficiency. Lamps must be replaced on a regular basis, while the external surfaces and screens of lighting fixtures in these spaces have to be cleaned.

In relation to the lighting comfort in these spaces, the results obtained by applying objective criteria- the measurements taken on board- and those gleaned subjectively from the surveys distributed to crew coincided in 57 % of the cases. Where this was especially the case was in the control bridge, cargo holds, engine room and lounge/ canteen, whereas discrepancies arose in the galley, cabins and engine control room.

At the same time, there is common ground in 72 % of the spaces when one compares mandatory regulations on land and at sea. The objective assessment only differed in two types of spaces: the lounge/canteen and control bridge.

Only 14 % the crew (though subjective criteria) felt that the lighting that fulfilled regulations and recommendations was unsuitable. At the same time it is interesting to see that the crew were satisfied with the lighting in the engine control room and galley, even though it did not fulfil the objective criteria or the guidelines.

In the places where visual display screens were used (control bridge and engine control room) the recommendations were not being followed. Nevertheless crew members considered these spaces comfortable.

Table 13: Comparisons of whether rules and/or recommendations for the light environment have been met in different vessel spaces.

SPACE	FULFILS COMFORT CRITERIA			
	SUBJECTIVE	OBJETIVE		
	SURVEY ON CONFORT	Mandatory regulations	Reference regulations	
		(ABS, 2014)	(AENOR, 1984; AENOR,1985)	(CEN, 2012a)
CONTROL BRIDGE	Yes	Yes	No	No
CARGO HOLDS	No	No	No	Not implemented
ENGINE ROOM	No	No	No	Not implemented
CONTROL ENGINE ROOM	Yes	No	No	No
GALLEY	Yes	No	No	No
LOUNGE-CANTEEN	Yes	Yes	Not implemented	No
CABINS	No	Yes	Not implemented	Yes

Source: Authors.

Table 14: Summary of how rules and/or recommendations for the light environment have been fulfilled in different spaces of the vessel.

CONTROL BRIDGE	Fulfils Classification Society regulations (ABS, 2014), but does not fulfil (AENOR, 1984; CEN, 2012). **Subjectively**, it is felt there is a comfortable light environment, although more natural sunlight and fewer annoying reflections are desired.
CARGO HOLDS	Does not fulfil (ABS, 2014). **Subjectively**, light environment is considered not so comfortable.
ENGINE ROOM	Does not fulfil the regulations or recommendations. **Subjectively**, there seems to be an uncomfortable light environment.
ENGINE CONTROL ROOM	Does not fulfil the regulations or recommendations, although, **subjectively**, it is felt there is a comfortable light environment.
GALLEY	Do not fulfil the recommendations or the regulations. **Subjectively**, the environment is considered comfortable, although it would be desirable to have more natural sunlight and fewer reflections.
LOUNGE-CANTEEN	Fulfils the regulation but not the recommendations. In **subjective** terms, the environment is deemed uncomfortable. This is possibly because of an excess in artificial light, while the crew members prefer more natural sunlight. They would also like to be able to adjust the luminance from artificial lighting
CABINS	Fulfil the regulation but do not follow the recommendations. Subjectively, the environment is seen as uncomfortable. This is possibly because of an excess in artificial light, while the crew members prefer more natural sunlight. They would also like to be able to adjust the luminance of artificial lighting.

Source: Authors.

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