J-STAGE Advanced published date: June 28, 2016, doi: 10.2150/jlve.IEIJ150000568

Research Note

Quality of Lighting in Hospital Environments: A Wide Survey Through in Situ Measurements

Francesco LECCESE*, Carlo MONTAGNANI**, Sergio IAIA*, Michele ROCCA* and Giacomo SALVADORI*

* **Lighting and Acoustics Laboratory (LIA), Department of Energy Engineering, Systems, Territory and Constructions (DESTeC), University of Pisa**
** **Head of Prevention and Protection Service, Tuscany Public Health Company "Pisa 5"**

Received August 4, 2015, Accepted March 30, 2016

ABSTRACT

In hospital buildings, such as in other large and multi-purpose buildings, a wide variety of work environments can be distinguished, each of which characterized by specific visual tasks. In hospitals the visual tasks are often very demanding and consequently the lighting should be functional to ensure efficiency, safety, hygiene and well-being of medical and auxiliary staff, during the development of their activities. For this type of buildings the activity of *in situ* measurements is strongly recommended in order to evaluate the quality of lighting and also to perform a lighting risk assessment. In this paper an extensive lighting measurements campaign in a hospital is described. The hospital used as a case study is the "Felice Lotti" in Pontedera (Pisa district, Tuscany Region, Italy) where illuminance and luminance measurements have been carried out for different environments with different uses typically found in hospitals. The measurement results are described and discussed in detail, with particular reference to the compliance with the requirements imposed by the technical standards.

KEYWORDS: hospital lighting, visual work environment, illuminance measurements, luminance measurements, lighting conditions assessment

1. Introduction

The assessment of lighting conditions of the working environment, and in particular of the workstations, must be carried out starting by a thorough and complete analysis of visual tasks that characterize the activity performed[1)–3)]. The European Standard EN ISO 6385 defines "work environment" as the set of physical, chemical, biological, organizational, social and cultural factors that surround the worker[4)]. The lighting conditions, together with the microclimate and air quality can significantly affect the attainment of the comfort and also the attitude of the workers[5)–7)].

Within the main object of vision, the "visual task" is defined in EN ISO 6385 as the set of visual elements of the performed activity[4)]. The analysis of visual tasks should:

- provide information regarding the visual task done, or more generally, the various visual tasks performed;
- indicate the mode of use of related equipment;
- allow to identify a hierarchy of priorities among the visual tasks performed.

For each visual task is necessary to identify the "task area", defined as the surface on which the visual task is placed[8)]. This is the surface on which the level of average illuminance indicated in the technical standards must be maintained. In any case, the lighting of a workplace should ensure optimal conditions for work performance even when the worker looks away from the task area. The essential requirements that should be met for proper lighting of the working environment or workstation, are concerning to[9)]:

- visual performance, since the workers should be able to perceive the object of vision unequivocally with speed and accuracy;
- visual comfort, as the environment should meet physiological, psychological and well-being needs, helping to significantly increase productivity;
- safety, which involves a safe and ready discernment of the dangers inherent in the work environment.

In order to check the fulfillment of the essential requirements it is necessary to refer to specific operating parameters, both quantitative and qualitative, that can be interpreted as performance indicators[1)–4)]. The lighting parameters which allow an accurate lighting evaluation of a given work environment, are[9)]: the illuminance level, the illuminance uniformity, the luminance distribution, the daylight availability, the prevention of glare, the color rendering and the color temperature.

doi: 10.2150/jlve.IEIJ150000568

Table 1 Minimum values of average maintained illuminance (E_m) and of average daylight factor (D_m) according to the Circular of the Italian Ministry of Public Works No. 13011 (1974).

Minimum values of average maintained illuminance (E_m) for artificial lighting in hospitals	
Type of visual task	E_m (lx)
Lighting on general working plane or medical observation (excluding the operating table)	300
Lighting on the working plane in the reading rooms and in the offices	200
Lighting in meeting rooms, sports halls, etc. (measured on an ideal working plane placed 60 cm above the floor)	100
Lighting in the corridors, stairs, restrooms, hallways, dressing rooms, etc. (measured on an ideal working plane placed 10 cm above the floor)	80
Minimum values of average daylight factor (D_m) in hospitals	
Type of room	D_m (%)
Wards, examination rooms, laboratories	3
Sports halls, dining rooms	2
Offices, corridors, hallways, stairs	1

In hospital environment, different activities can be distinguished, consequently in the design stage of the lighting system, different needs of patients, visitors, medical and auxiliary staff should be consider. The lighting in hospital must be functional to ensure efficiency, safety, hygiene and well-being of users and operators, during the development of their activities[10)11)], the achievement of these aims can be evaluated, for existing lighting systems, mainly through ***in situ*** measurements, which can also be used for a detailed lighting risk assessment[12)13)].

In Italy, the lighting requirements for the hospitals were initially regulated by the Circular of the Ministry of Public Works No.13011 (1974), about the technical requirements for hospital buildings. The lighting requirements, specified in the Circular 13011 are summarized in Table 1. They are relating to the artificial lighting, with minimum values of average maintained illuminance (E_m), and to the daylighting, with minimum values of average daylight factor (D_m).

Currently, the European Standard EN 12464-1[9)] is the reference that specifies lighting requirements of indoor workplaces for visual comfort and visual performance purposes. By way of example, some reference values

Table 2 Examples of lighting requirements for health care premises according to EN 12464-1[9)].

Type of room, task or activity	E_m (lx)	U_0	UGR_L	R_a	Specific requirements
Local for general use (Source: Table 5.37, EN 12464-1)					Too high luminances in the patients' visual field shall be prevented.
Waiting rooms	200	0.40	22	80	
Corridors during the day and cleaning	100	0.40	22	80	Illuminance at floor level.
Wards, maternity wards (Source: Table 5.39, EN 12464-1)					Too high luminances in the patients' visual field shall be prevented.
General lighting	100	0.40	19	80	Illuminance at floor level. For night lighting a minimum value of E_m=5 lx is required.
Reading lighting	300	0.70	19	80	
Simple examinations	300	0.60	19	80	
Examination and treatment	1000	0.70	19	90	
Scanner rooms (Source: Table 5.43, EN 12464-1)					
General lighting	300	0.60	19	80	
Scanners with image enhancers and television systems	50	—	19	80	For the work at display screen equipment, special requirements are reported in a specific section.
Treatment rooms (general) (Source: Table 5.45, EN 12464-1)					
Endoscopy rooms, medical baths, Massage and radiotherapy	300	0.60	19	80	
Operating areas (Source: Table 5.46, EN 12464-1)					
Pre-op and recovery rooms	500	0.60	19	90	
Operating theatre	1000	0.60	19	90	
Laboratories and pharmacies (Source: Table 5.49, EN 12464-1)					
General lighting	500	0.60	19	80	
Color inspection	1000	0.60	19	90	$6000 \leq T_C \leq 6500$ K

doi: 10.2150/jlve.IEIJ150000568

extracted from EN 12464-1 for health care premises are shown in Table 2. In Table 2 are indicated: the minimum values of average maintained illuminance (E_m), the illuminance uniformity (U_0), the color rendering index (R_a) of the lamps and the maximum values of discomfort glare (UGR_L). These limit values are specified for the most part of the usual visual tasks, including those that involve the use of display screen equipment[14)15)]. The minimum values of E_m (indicated in the EN 12464-1), vary from extremely low levels (e.g. 5 lx, for night lighting) to levels sufficient for an accurate perception of the environment (e.g. 100 lx, for general lighting) up to very high levels (e.g. 1000 lx, for examination and treatment performed by medical staff).

General lighting should be sufficient to allow routine tasks both for the medical and auxiliary staff and for the patients[12)16)–18)]. General lighting plays also an important role to create a pleasant and reassuring environment[10)11)]. For the purposes of lighting comfort in wards, the following different, sometimes conflicting, needs should be considered:

- ensure adequate daylighting, a visual contact with outside and absence of glare, for patients and visitors;
- ensure adequate artificial lighting to verify health status of the patient (even with direct visual observation) and adequate lighting levels to bring necessary medical care to the patient.

The lighting integrated in each bed (indirect lighting and reading lighting from headboard) should be able to provide adequate lighting to the patients in order to perform personal activities such as reading or other manual activities. Since this illumination is generally direct and personal, it is important that in the larger rooms this does not constitute a source of disturbance for guests on surrounding beds. For the patients, often forced to the horizontal position on the bed, assumes great importance the color and the reflection factor of the ceiling, which must be not less than 0.7[11)12)].

The lighting for medical examinations or treatments must be able to provide adequate light for the medical and auxiliary staff to perform examination and care activities on the patients. In view of the difficulty of the visual task, it is important to have a lighting system that guarantees the absence of glare against the staff and to use lighting sources with color rendering as close as possible to the natural light.

The comparison between the requirements specified in EN 12464-1[9)] and the results obtained through *in situ* measurement campaigns, carried out in different lighting scenarios, can be used to evaluate the quality of the lighting for an hospital[10)12)].

In this paper an extensive lighting measurement campaign in an hospital is described. The hospital used as a case study is the "Felice Lotti" in Pontedera (Pisa District, Tuscany Region, Italy) where illuminance and luminance measurements have been carried out for different environments with different uses. The lighting measurement campaign is a part of a wide investigation carried out by the Authors aimed to evaluation of the lighting[2)12)15)] and artificial optical radiation[19)–21)] risk assessment in the hospital of the Tuscany Region in Italy. The high number of *in situ* measurements has allowed a detailed verification of the compliance with the requirements imposed by the technical standards for different rooms and different visual tasks and it has also allowed to have an overall assessment of the lighting quality of the hospital.

2. Lighting analysis of the Hospital "Felice Lotti" through an in situ measurements campaign

The Hospital "Felice Lotti" is an important health care premise of the Tuscany Region and it has undergone recent renovations. It consists of 10 pavilions, as shown in Figure 1, with approximately 300 beds and currently serves a catchment area of approximately 110.000 habitants. The lighting measurement activity has involved different environments for use and visual tasks performed by medical/nursing staff.

2.1 Case study description

In this paper the Authors describe the activities carried out in eight rooms chosen as study cases for the evaluation of the quality of lighting, they are (see Figure 1):

- a room in the ward of Orthopedics and Traumatology (room 1, pavilion H, second floor);
- a brief intensive observation room (room 2, pavilion H, second floor);
- a corridor in the transfusion center (room 3, pavilion I, first floor);
- a corridor for the connection of pavilions H–F–I (room 4, first floor);
- a reception center (room 5, pavilion E, ground floor);
- a laboratory for chemical analysis (room 6, pavilion I, first floor);
- an operating room of ambulatory surgery (room 7, pavilion I, ground floor);
- an endoscopy room (room 8, pavilion I, ground floor).

The measurement activity began with a preliminary stage, where different information, about each analyzed room, have been collected, in particular: geometric data, main visual tasks with complete survey of color surfaces and lighting devices (luminaires and lamps) functionally dedicated, size and orientation of windows, features of possible shading system for the windows (e.g. rolling shutter, brise-soleil, external obstruction).

doi: 10.2150/jlve.IEIJ150000568

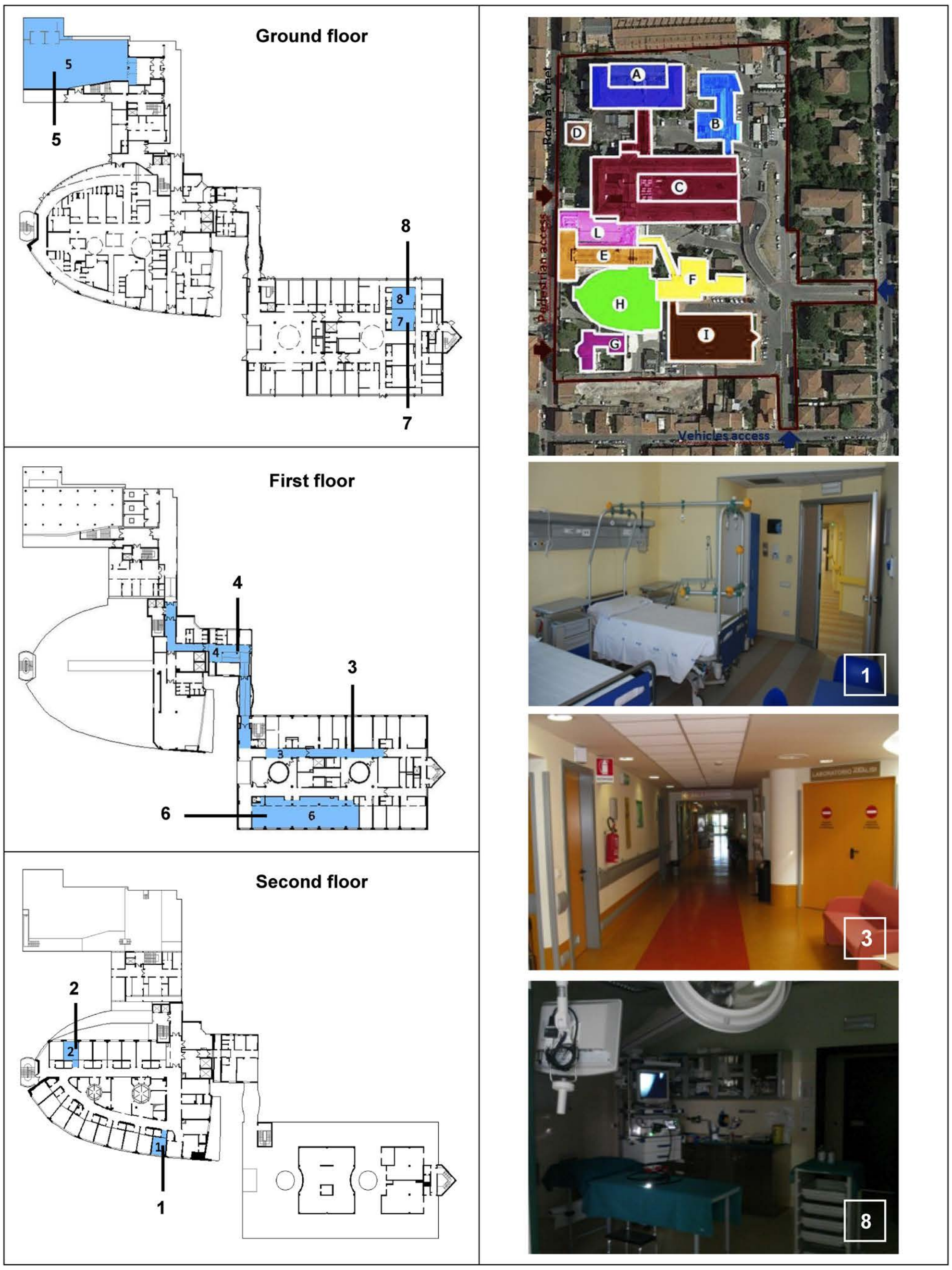

Figure 1 Hospital "Felice Lotti" of Pontedera (Pisa district, Tuscany region, Italy). Left: plans of the Hospital with the identification of the analyzed rooms (1-room in the ward of Orthopedics and Traumatology, 2-brief intensive observation room, 3-corridor in the transfusion center, 4-corridor for the connection of pavilions H–F–I, 5-reception center, 6-laboratory for chemical analysis, 7-operating room of ambulatory surgery, 8-endoscopy room). Right: aerial view with the indication of the different pavilions and pictures of some analyzed rooms.

2.2 Methodology used for the measurement activity

The lighting measurement campaign has been focused on illuminance measurements on the working planes and on luminance measurements in the main directions of view for the most important visual tasks. In hospitals luminance measurements can be very significant[12)14)18)], for example in: operating rooms, diagnostic rooms, VDT workstations, and corridors of connection.

The in situ measurements have been conducted with portable instruments made available by Lighting and Acoustics Laboratory of the University of Pisa: a luxmeter Delta Ohm model HD2101.1 and a luminancemeter Hagner model L-202. These instruments have an accuracy class "B" according to the Italian Technical Standard UNI 11142[22)]. The measurements has been carried out following the procedures set out in the technical regulations currently in force, particularly for indoor work places[9)12)]. In particular, the illuminance

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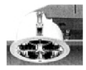
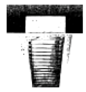
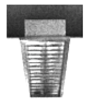
measurements have been carried out on a grid point, with minimum number of points and minimum distance between points which are function of the working plane size, according to the EN 12464-1[9].

In Table 3, for each analyzed room, the floor area (S), the type of luminaire and lamp, the luminaire electrical power (P) and the electrical power for floor surface unit (P^*) have been summarized. It should be noted that P^* value represents a significant indication for the evaluation of energy performance of the lighting system, as indicated in the EN 15193[23].

2.3 Overview of the results

In Table 4 a summary of the results of illuminance measurements, obtained for all the analyzed rooms, is shown. The results are referred to artificial lighting

Table 3 List of installed luminaires and lamps, for each of the analyzed rooms.

ID	Room	S (m^2)	Type of luminaire/lamp		R_a	T_C (K)	P (W)	P^* (W/m^2)
L1	Room in the ward of Orthopedics and Traumatology	21	No. 2 recessed luminaires/compact fluorescent lamps 2×26W		80	4000	292	19.9
L2			No. 2 headboard luminaires/fluorescent tubes 1×58W and 2×18W		80	4000		
—	Brief intensive observation room	21	Same of ID L1				104	4.9
L3	Corridor in the transfusion center	79	No. 24 recessed luminaires/compact fluorescent lamps 2×18W		80	3000	432	5.5
L4	Corridor for the connection of pavilions H–F–I	177	No. 19 recessed luminaires/compact fluorescent lamps 2×26W		85	4000	1186	6.7
L5			No. 2 recessed luminaires/fluorescent tubes 4×18W		80	3000		
L6			No. 3 wall mounted luminaires/compact fluorescent lamps 2×9W		80	3000		
L7	Reception center	352	No. 18 luminaires suspended from the ceiling/metal halide lamp 1×150W		90	4200	4188	11.9
L8			No. 12 wall mounted luminaires/metal halide lamp 1×70W		90	4200		
L9			No. 6 luminaires suspended from the ceiling/fluorescent tubes 2×54W		90	4200		
L10	Laboratory for chemical analysis	234	No. 27 recessed luminaires/fluorescent tubes 2×58W		85	4000	3132	13.4
L11	Operating room of ambulatory surgery	31	No. 9 recessed luminaires/fluorescent tubes 2×36W		85	4000	788	25.4
L12			No. 1 scialytic lamp/gas discharge lamps 2×70W		95	4300		
L13	Endoscopy room	31	No. 9 recessed luminaires/fluorescent tubes 2×36W		85	4000	718	23.2
L14			No. 1 scialytic lamp/gas discharge lamp 1×70W		95	4300		

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condition on the main working planes (located at height h above the floor). In Table 5 the results of illuminance measurements obtained for the rooms with glazed surfaces in integrated lighting condition (both artificial lighting and daylighting) are shown.

The values of the average measured illuminance (E_m), indicated in Tables 4 and 5, have been obtained using the equation[9)12)]:

$$E_m = (E_1 + E_2 + \cdots + E_N)/N$$

where E_i is the illuminance value measured at the generic i point on the measurement grid and N is the total number of the measurement points for each working plane. The values of illuminance uniformity (U_0) have been calculated using the equation[9)]:

$$U_0 = E_{\min}/E_m$$

Table 4 Overview of the results of the Illuminance measurements in artificial lighting conditions.

Room	Working plane (H=horizontal, V=vertical)	h (cm)	E_m (lx)	U_0
Room in the ward of Orthopedics and Traumatology	Floor (H)	20	171	0.61
	Bed (H, Northern side)	90	231	0.70
	Bed (H, Southern side)	90	207	0.95
	Perimetric wall (V, Northern side)	170	198	0.65
	Perimetric wall (V, Eastern side)	170	151	0.66
Corridor in the transfusion center	Floor (H)	20	82	0.24
Laboratory for chemical analysis	Floor (H)	20	420	0.19
	Keyboard of the workstation* (H)	80	492	0.57
	Desk of the workstation* (H)	100	285	0.65
	Display* (V)	120	195	0.67
	Chassis of the display* (V)	120	1158	0.94
	Desk of the workstation** (H)	80	202	0.64
	Display** (V, display 1)	120	200	0.85
	Display** (V, display 2)	120	285	0.60
	Display** (V, display 3)	120	185	0.65
	Display** (V, display 4)	120	470	0.62
Operating room of ambulatory surgery	Floor (H)	20	528	0.45
	Operating bed (H, with scialytic lamp switched off)	100	868	0.77

*Measurements carried out on a workstation equipped by No.1 display screen equipment.
** Measurements carried out on a workstation equipped by No.4 display screen equipment.

Table 5 Overview of the results of Illuminance measurements in integrated (artificial and day-) lighting conditions.

Room	Working plane (H=horizontal, V=vertical)	h (cm)	E_m (lx)	D_m (%)
Corridor for the connection of pavilions H–F–I*	Floor (H, portion of pavilion H)	20	117	23.5
	Floor (H, portion of pavilion F)	20	129	
	Floor (H, portion of pavilion I)	20	3669	
Reception center**	Floor (H, central zone)	20	1149	13
	Floor (H, perimetric zone)	20	162	
	Floor (H, zone near to the stairs leading to upper floors)	20	207	
	Perimetric wall (V, white painted)	150	400	
	Perimetric wall (V, yellow painted)	150	98	
	Perimetric wall (V, red painted)	150	135	

*Glazed surface: 6.4 m^2 with Southern exposition, measurement carried out 2014/05/08 at 3:40 p.m. with overcast sky conditions.
**Glazed surface: 259.0 m^2 with Western exposition, measurement carried out 2014/05/18 at 11:40 a.m. with overcast sky conditions.

doi: 10.2150/jlve.IEIJ150000568

where E_{min} is the minimum measured illuminance on the working plane due to artificial lighting.

Given the large amount of data available, in the next few sections some of the most significant measurement results are discussed in detail, dividing those obtained for illuminance from those obtained for luminance. The results are discussed in particular for: the room in the ward of Orthopedics and Traumatology (room 1, Figure 1), the corridor for the connection of pavilions H–F–I (room 4, Figure 1) and the endoscopy room (room 8, Figure 1).

3. Illuminance measurements for the room in the ward of Orthopedics and Traumatology

The rooms in the wards represent for the medical and auxiliary staff a working environment at which are connected visual tasks that require a high degree of precision and speed in perception of details, often of small sizes[10)12)]. The main performed activities are: daily care of the patient, both day and night, distribution of medications and foods, medical inspections, filling of medical records and in all these activities the lighting plays a key role.

The analyzed room (room 1, pavilion H, second floor, see Figure 1) has a floor area of 21 m^2, a useful height of 3.0 m and a window of 4 m^2 with Southern exposition. The window has a metal frame and single glazing (without low-emissivity treatments) characterized by a luminous transmission coefficient t=0.9. The percentage of the frame surface with respect to the overall window surface is about 20% and it is equipped with internal blue curtains and external rolling shutters. The floor is covered with gray ceramic tiles, the walls are cream colored and the ceiling is made of plaster-cardboard

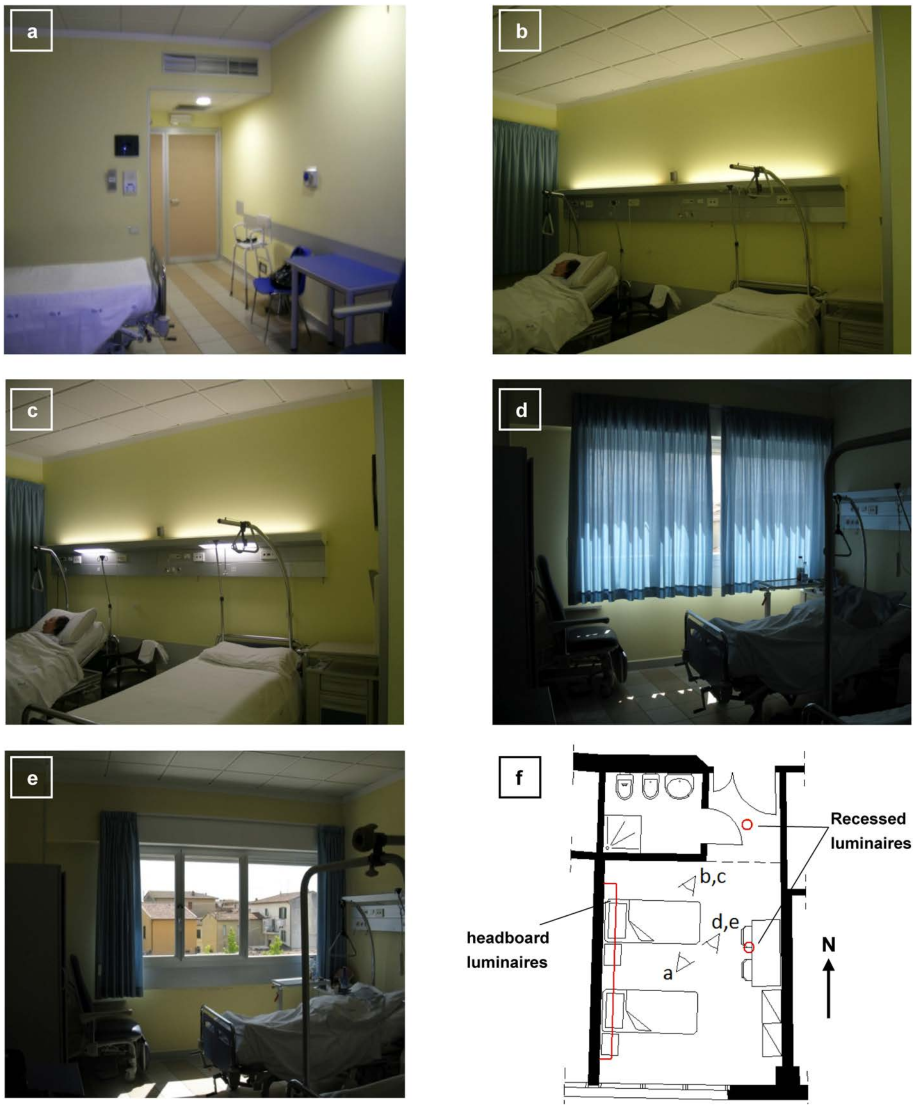

Figure 2 Images of the room in the ward of Orthopedics and Traumatology: a) Scenario 1-general lighting, b) Scenario 2-general lighting and indirect lighting from headboard, c) Scenario 3-general lighting, indirect and reading lighting from headboard, d) Scenario 4-daylighting with closed curtains, e) Scenario 5-daylighting with opened curtains, f) plan view of the room with the directions of framing of the pictures.

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panels in white color. Furnishings include two beds in steel and laminate, two nightstands in two-tone blue/gray, a cupboard in double compartment for patients, a table and two chairs in blue color. Inside the room are installed two recessed luminaires on the ceiling and two headboard luminaires, one for each bed, with three lamps (with separate switching, one indirect lamp and two reading lamps), see Table 3 (luminaires ID L1 and ID L2). The staff, who provide activities are medics, nurses and other auxiliary staff (physical therapists and observers).

3.1 Discussion of artificial lighting analysis

In order to obtain significant information about the quality of lighting, the illuminance measurements have been performed in different lighting scenarios. For

Table 6 Room in the ward of Orthopedics and Traumatology: results of illuminance measurements on main working planes for different lighting scenarios.

Working plane (H=horizontal, V=vertical)		h (cm)	E_m (lx)		U_0	
			Measured	Standard	Measured	Standard
SCENARIO 1: general lighting						
Floor (H)		20	72	100	0.33	0.60
Bed (H, Northern side)		90	63	300	0.80	0.70
Bed (H, Southern side)		90	43	300	0.91	0.70
Perimetric wall (V, Northern side)		170	37	300	0.22	0.60
Perimetric wall (V, Eastern side)		170	67	300	0.25	0.60
SCENARIO 2: general lighting and indirect light from headboard						
Floor (H)		20	171	100	0.61	0.60
Bed (H, Northern side)		90	231	300	0.70	0.70
Bed (H, Southern side)		90	207	300	0.95	0.70
Perimetric wall (V, Northern side)		170	198	300	0.65	0.60
Perimetric wall (V, Eastern side)		170	151	300	0.66	0.60
SCENARIO 3: general lighting, indirect and reading lights from headboard						
Floor (H)		20	234	100	0.65	0.60
Bed (H, Northern side)		90	381	300	0.91	0.70
Bed (H, Southern side)		90	315	300	0.89	0.70
Perimetric wall (V, Northern side)		170	238	300	0.67	0.60
Perimetric wall (V, Eastern side)		170	180	300	0.69	0.60
SCENARIO 4: daylighting with closed curtains						
Day: 2014/04/21 Hour: 11:00 a.m.	Floor (H)	20	77	Not applicable	0.26	Not applicable
	Bed (H, Northern side)	90	63		0.55	
	Bed (H, Southern side)	90	88		0.31	
Day: 2014/05/13 Hour: 3:00 p.m.	Floor (H)	20	265		0.15	
	Bed (H, Northern side)	90	225		0.09	
	Bed (H, Southern side)	90	325		0.08	
SCENARIO 5: daylighting with opened curtains						
Day: 2014/04/21 Hour: 11:00 a.m.	Floor (H)	20	294	Not applicable	0.48	Not applicable
	Bed (H, Northern side)	90	787		0.41	
	Bed (H, Southern side)	90	915		0.36	
Day: 2014/05/13 Hour: 3:00 p.m.	Floor (H)	20	510		0.34	
	Bed (H, Northern side)	90	642		0.50	
	Bed (H, Southern side)	90	751		0.35	

doi: 10.2150/jlve.IEIJ150000568

artificial lighting, the scenarios which have been considered are:

- scenario 1: general lighting, with recessed luminaires (see Table 3, ID L1) switched on;
- scenario 2: general lighting and indirect lighting from headboard, with recessed luminaires switched on and headboard luminaires (see Table 3, ID L2) partially switched on;
- scenario 3: general lighting, indirect and reading lighting from headboard, with recessed luminaires and headboard luminaires fully switched on.

Some pictures of the different described lighting scenarios are shown in Figure 2. In Table 6, the results of illuminance measurements on the main working planes (floor, upper surfaces of the beds, perimetric vertical walls) are shown.

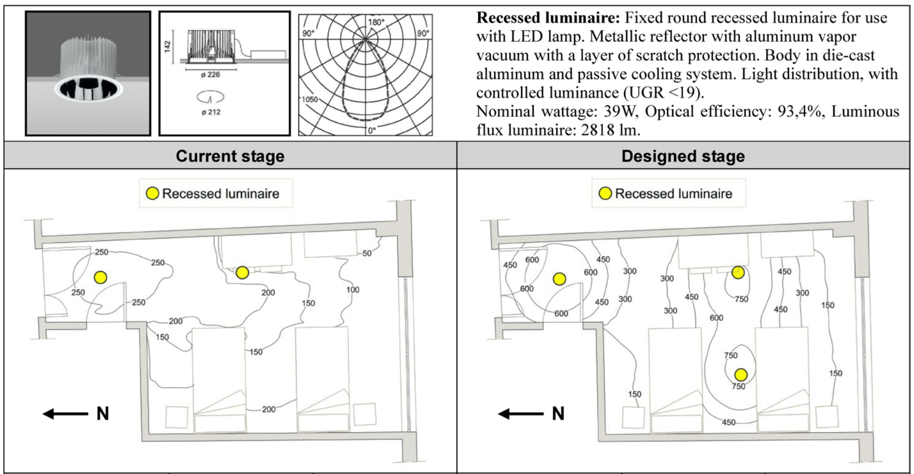
In Table 6 is also reported the illuminance standard values fixed by the EN 12464-1[9]. From the comparison between measured and standard illuminance values it is possible to pointed out some important considerations about the lighting of the room.

In the scenario 1, the average illuminance values on the beds and walls not satisfy the standard requirements, while for the scenarios 2 and 3 the required values at floor level are reached (see Table 6). With regard to the value of 300 lx indicated for routine tasks, it is reached on the working planes only in the scenario 3, when all the luminaires are switched on (see Table 6). The illuminance uniformity requirement is verified only in the scenarios 2 and 3 (see Table 6). The recessed luminaires have a unified glare rating value (*UGR*), evaluated by tabular method, equal to 26.4, higher than the limit (see Table 2). The lamps installed in the luminaires have a color rendering *Ra*=80, this value is adequate for the most of the activities performed in the room but is not sufficient for examination and treatment (see Table 2). It can be concluded that the artificial lighting system is not very suitable for the analyzed room, since is able to satisfy only few requirements imposed by the standard.

Following the measurement results, different weaknesses have been found for the artificial lighting system, that could have been avoided through a detailed lighting design. Main lighting issues, that appear in the analyzed hospital room, are: the low illuminance values on the walls and on the beds, the poor illuminance uniformity on the floor in some scenarios and the glare due to the recessed luminaires.

In order to show how the lighting issues could be solved, the analyzed room has been modelled in the software Dialux[24] and the three lighting scenarios have been simulated. The simulation results have been compared with the measurement results. Simulation results show deviations with respect to the measurement results lower than 5% for all the simulated scenarios. In Figure 3, the comparison between the measured and the simulated average illuminance values (at current stage), on the main working planes, are shown for the scenario 2.

In order to solve the lighting issues, the replacement of the existing recessed luminaires with new recessed luminaires equipped with LED lamp and the addition



Working plane	measured		simulated		Working plane	standard		simulated	
	E_m (lx)	U_0	E_m (lx)	U_0		E_m (lx)	U_0	E_m (lx)	U_0
Floor	171	0.61	178	0.62	Floor	100	0.60	278	0.75
Bed (Northern side)	231	0.70	236	0.72	Bed (Northern side)	300	0.70	388	0.80
Bed (Southern side)	207	0.95	215	0.95	Bed (Southern side)	300	0.70	320	0.95

Figure 3 Current stage and design stage for the artificial lighting of the room in the ward of Orthopedics and Traumatology (see Figure 2b, Scenario 2): LED luminaire features (up), simulation results of the current stage (left), simulation results of the designed stage (right). The isolux curves are referred to the floor.

doi: 10.2150/jlve.IEIJ150000568

of one more recessed luminaire has been proposed. The main features of the new recessed luminaires are shown in Figure 3. In Figure 3, the simulation results for the scenario 2 (working plane coincident with the floor), with new recessed luminaires (at design stage), are shown. From the comparison between the design stage and the current stage, it possible to observe a significant improvement of the illuminance levels on the main working planes (see Figure 3). In particular the increase of the average values of illuminance and illuminance uniformity are evident, especially in the area where the beds are located and in which the staff has to carried out the most important activities for the patients. The design stage allows to meet the requirements fixed by the technical standard[9], also in term of glare, because the new recessed luminaires have a controlled distribution of light emission with *UGR* (evaluated by tabular method) lower than 19 (see Table 2).

This example helps to point out that very often, with simple and carefully designed revisions of lighting systems, the improvement of the lighting conditions can be obtained, passing from non-compliance with the requirements of technical standards to their conformity. It is interesting to note that the replacement of the existing recessed luminaires with new luminaires equipped with LED can also allow a significant increasing of the energy efficiency of the lighting system[25].

3.2 Discussion of daylighting analysis

For the daylighting, the scenarios which have been considered are:

- scenario 4: daylighting with closed curtains;
- scenario 5: daylighting with open curtains.

Some pictures of the different described lighting scenarios are shown in Figure 2. In Table 6, the results of illuminance measurements on the main working planes are shown. The measurements has been carried out on the same grid point used for artificial lighting analysis.

The daylight factor D_m has been evaluated using the equation[10,12]:

$$D_m = E_m / E_0$$

where E_m and E_0 are respectively the average measured illuminance inside the room (considering the floor as working plane) and the illuminance measured outdoor on a horizontal plane shielded by the direct sunlight.

Variability of natural lighting during the day and the presence of only one window facing South do not favor an adequate lighting uniformity. In any cases considering, for outdoor illuminance the values of 8500 lx (11:00 a.m.) and 12600 lx (03:00 p.m.), measured in overcast sky conditions, for the daylight factor with opened curtains (see Table 6, scenario 5) average values of 3.5% and 4.0% have been respectively obtained. These values fulfill the minimum requirement of 3% for the rooms in the wards (see Table 1).

4. Luminance measurements for the corridor (connection of pavilions H–F–I) and for endoscopy room

The corridors are physical spaces frequently used by patients, visitors, medical and auxiliary staff as well as being place of relationship. Their function is to create connecting paths between various departments of the hospital, between different areas of the same department, between zones of waiting, permanence and working. The size and complexity of hospitals make necessary the organization into paths to facilitate user's orientation. To this scope, lighting can be used as a guide to focal points of the paths for users accessing to the structure for the first time, which ignore the functional organization of the hospital[10,12,18]. The luminaires in these spaces should ensure, in term of features and number, the following main requirements:

- enough lighting to perceive the whole environment;
- enough lighting to avoid discontinuity of lighting with adjacent rooms, so that to avoid problems related to adaptation of the eye to variations in luminance;
- illuminance levels variable throughout the day, particularly between daytime and nighttime;
- uniform distribution of illuminance even when the illuminance level is reduced;
- absence of direct and reflection glare phenomena, both for the users which walk along the corridor and for the patients which go through the corridor in supine position on stretcher, and also for those who stay within the chambers when doors are opened.

In the case of the endoscopy room, the medical staff always needs the maximum concentration and must have perfect lighting conditions to facilitate very demanding visual tasks[12,26,27], which require indirect lighting. In the EN 12464-1[9], limit values of luminance to prevent direct and reflected glare on display screen equipment are specified (with special reference to vertical display screen equipment). Should be noted that surfaces of modern displays are shielded to not cause annoying reflections even with luminance levels are higher than those recommended by the standards. In terms of luminous environment, for this type of room it is necessary to avoid:

- the presence of light sources in the field of view of the operator;
- the possibility of reflections on shiny surfaces;
- the presence of light sources with different color temperatures.

In this room, hygiene and cleanliness are elements of everyday routine and in the choice of the luminaires

doi: 10.2150/jlve.IEIJ150000568

also this peculiarity should be considered.

4.1 Discussion of luminance analysis for the corridor

The corridor, for which the measurements results are shown in this paper, is used for the connection between the pavilions F, H and I (room 4, first floor, see Figure 1). The lighting solution adopted in this room is very common in the Italian hospitals[10)12)], and it is based on the use of both ceiling mounted luminaires (or recessed luminaires) and wall mounted luminaires with indirect light, with different ignition devices, in order to ensure different lighting conditions during the day and the night.

In Table 7, the results of illuminance measurements on the main direction of view, that can occur in the analyzed room, are shown. In order to reproduce the actual viewing conditions of the users across the corridor, the

Table 7 Luminance and illuminance measurements for the corridor (connection of pavilions H–F–I).

Target position	Luminance				Illuminance		
	Luminancemeter position	L (cd/m^2)	R		E_V (lx)	E_H (lx)	M
B_1	S_1	20	—				
P_1		30	L_{P1}/L_{B1}	1.5	191	230	0.83
P_2		340	L_{P2}/L_{B1}	17	182	14500	0.01
P_3		36	L_{P3}/L_{B1}	1.8	162	980	0.17
B_2	S_2	52	—				
P_4		40	L_{P4}/L_{B2}	0.8	240	400	0.60
P_5		138	L_{P5}/L_{B2}	2.6	890	980	0.91
P_6		107	L_{P6}/L_{B2}	2.1	530	14500	0.04
B_3	S_3	78	—				
P_7		16	L_{P7}/L_{B3}	0.2	88	195	0.45
P_8		14	L_{P8}/L_{B3}	0.2	55	90	0.61

Symbol key: P_x=person position (with x=1,2,…,8), B_y=background surface (with x=1,2,3), S_k=luminancemeter position (with k=1,2,3), L=measured luminance, R=calculated luminance ratio, E_V=vertical illuminance, E_H=horizontal illuminance, M=modelling index.

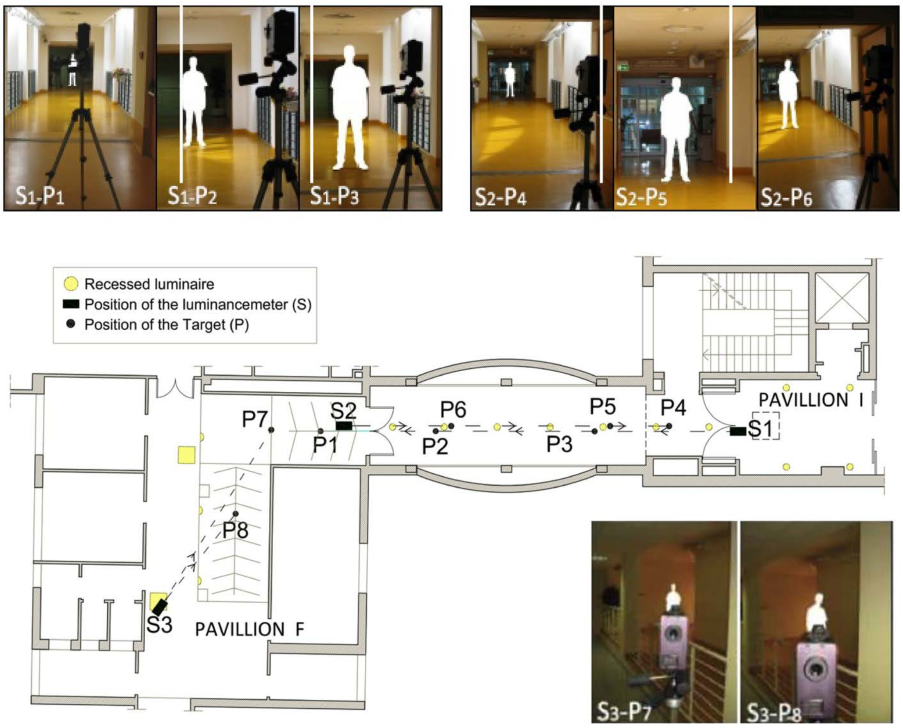
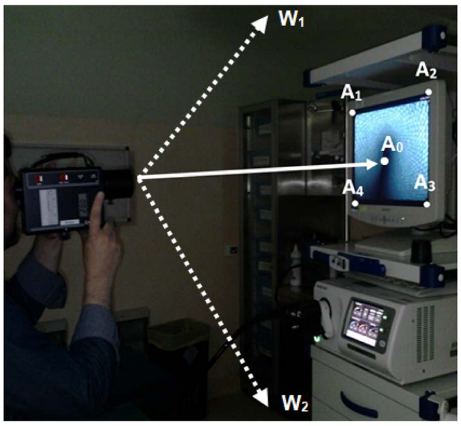


Figure 4 Corridor connection pavilions H–F–I: configurations used for the luminance measurements.

doi: 10.2150/jlve.IEIJ150000568

Table 8 Endoscopy room: luminance ratios between the central points of the screen (A_0) and the edges of the screen (A_x, with x=1,2,3,4) and the edge of the walls (W_y, with y=1,2).



Edge	L_{Ax} (cd·m^{-2})	L_{A0} (cd·m^{-2})	L_{Ax}/L_{A0}
A_1	35	3	0.08
A_2	22		0.14
A_3	12		0.25
A_4	7		0.43
Wall	L_{Wy} (cd·m^{-2})	L_{A0} (cd·m^{-2})	L_{Wy}/L_{A0}
W_1	2	3	1.5
W_2	1		3

measurements have been carried out placing the luminancemeter in 3 different positions (Figure 4, positions S1, S2, S3) and measuring the luminance values (L) on the body of a person (main task area, when a corridor is path). The person is placed at specific locations within the corridor (Figure 4, positions from P1 to P8). For each position of the luminancemeter, the luminance values of the background surfaces (B1, B2, B3) have been also measured, in order to calculate the luminance ratio (R) between the task area (the body of the person) and the background of the vision.

From the measurement results shown in Table 7 it can be seen that luminance ratios are generally within the range between 0.1 and 10, which is the suggested range by the technical standards[9)12)].

The measurements activity on the corridor has been completed with some illuminance measurements aimed to the calculation of the modelling index (M) for each analyzed position. The modelling index is a lighting parameter of fundamental importance to assess the quality of perception of three-dimensional objects. The modelling index takes into account the balance between diffuse and directional lighting and it is defined by the equation[9)]:

$$M = E_V / E_H$$

where E_V and E_H are respectively the vertical and the horizontal illuminances evaluated at the same point[9)12)]. For a uniform arrangement of luminaires modelling index must result between 0.3 and 0.6[9)]. From the results of modelling index, which are shown in Table 7, it is possible to noticed that, in some positions, the calculated index does not fall into the suggested range, because of the strong influence of the daylight. In this case, the possibility of shielding the large window surfaces, for example with shutters, would guarantee a significant increase of the luminous comfort.

4.2 Discussion of luminance analysis for the endoscopy room

In the endoscopy room, luminance measurements on a screen used to visualize the endoscopic images, have been carried out. The luminance values have been measured on the center point and on the edges of the screen, as indicated in Table 8, also on the surrounding of the visual task and on the background vertical wall[14)15)].

The measurement results are summarized in Table 8. The luminance ratios between the central point and the edges of the screen are not always within the range 0.1–10 suggested by the EN 9241-307[28)], on the contrary the luminance ratios between the center of the screen and the walls satisfied such Standard requirement. In the analyzed room the indirect lighting is provided by a scialytic lamp, that is oriented towards the opposite wall with respect to the screen position. It is obvious that the scialytic lamp is used in an improper manner and that a suitable lighting system, able to provide the amount of indirect light required by the operator, should be mounted.

5. Conclusions

The hospital is a complex structure usually composed by different environments which should be designed to focus attention on the patient, his needs and his health. In the hospital, the patients live and carry out the daily activities that their health states allow, including resting, eating meals, reading and receiving visits. The lighting for these spaces must be able to contribute in making the wards functional, pleasant and welcoming both perspective of the patient, forced from illness in an unfamiliar environment, and of the medical staff who carries out highly challenging activities.

In order to ensure the proper diagnosis and treatments and consequently patients healings, medical and auxiliary staff is also continuatively engaged in highly

doi: 10.2150/jlve.IEIJ150000568

challenging work activities. For them, lighting in the workplace is an essential aspect to allow an accurate and safe work, ensuring at the same time adequate levels of visual comfort, preventing visual fatigue and stress. In Italy, although there are standard values for lighting parameters since 1974, only in the early 2000s the impact of the quality of lighting on the work environment, in terms of health and safety of the workers, has been seriously considered. In order to conduct an evaluation of the quality of lighting and eventually determine some actions to improve it, the activity of *in situ* measurements is strongly recommended.

In this paper an extensive lighting measurement campaign in an hospital is described. The hospital used as a case study is the “Felice Lotti” of Pontedera (Pisa district, Tuscany Region, Italy) where illuminance and luminance measurements have been carried out for different rooms with different uses.

The measurement results have been described and discussed in detail, with particular reference to the evaluation of the compliance with the values imposed by the technical standards. From the measurement results it has been possible to highlight how the lighting in this type of environments is often too superficially considered in the design stage, in fact different non-compliance with the technical standards requirements have been highlighted. Very often such non-compliance could be avoided with simple precautions to be taken during the design stage.

Acknowledgments

The measurement activity was partially carried out during the University training internship of Dr. Sergio Iaia at the Hospital “F. Lotti” in Pontedera (Pisa district). The internship was authorized by the Tuscany Public Health Company “Pisa 5” (internship Tutor: Dr. Carlo Montagnani, Head of Prevention and Protection Service). The Authors want to thank the staff of the hospital for their helpful and cooperation during the visits and the measurement activity.

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