Flexibility and Environmental Sustainability in Hospital Facilities

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ABSTRACT

Environmental sustainability in healthcare facilities is a priority objective because of the high environmental impact, all over the life cycle of hospital buildings and especially during the service life. This paper aims to give a contribution to environmental sustainability assessment of hospital facilities focusing on infill in hospital facilities, with regards to their short service life and flexibility required over time for these components (the word infill is used according to OB theory). Research analyzes hospital complex system identifying and classifying the different areas that shape it, on the base of two criteria influencing the flexibility requirements: technological-systems complexity level and intensity of care. This study uses these two criteria to pick out, in every functional area, what is "base" and what is "infill", in order to optimize the flexibility during service life and limit the environmental impact following the short service life of the infill. As a matter of fact the higher the technologic complexity and intensity care are, the stronger will be the presence of infill with short service life and, consequently, the environmental impact due to their continuous replacement/modification. The study of the flexibility environmental impact is done through the LCA methodology applied to the surgery block case study.

KEYWORDS
healthcare, system complexity, infill, environmental impact, indoor comfort

INTRODUCTION

Hospitals are characterized by a very high impact, at both physical and environmental level. Their pressure on environment is due to:

- environmental aspects and impacts of medical activity (process domain);
- specific indoor environment required for medical activity (functional domain);
- impact of hospital building (technical domain).

Environmental sustainability in the process domain

In the process domain, most critical aspects during operation stage of hospitals are production of waste, both solid and liquid, emission in air of polluting substances, production of ionizing radiation.

Italia and other country's regulations focus special attention on health and safety of building users (staff, patient, visitors); laws and norms take into account the indoor air quality and indoor environmental quality. Instead, external control (aimed to environment protection) has been less important till '90, when European community promoted some "proactive" tools to stimulate organizations in the adoption of self-control systems for pollution prevention and environmental performance improvement. One of that tools is the EMAS Scheme, Environmental Management and Audit Scheme, initially addressed to industrial site and then extended to all organizations that want to improve their environmental performances. EMAS is a Label recognized to all organizations that adopt an Environmental Management System. Procedure for certification is based on the following six steps:

- Initial environmental analysis, to define the state of fact;
- Statement of an environmental policy, to define environmental objectives;
- Statement of an environmental program, with measures that allow fulfilment of defined objectives;
- Adoption and using of the defined environmental management scheme;
- Auditing activity, to evaluate the system;
- Environmental Declaration, with a short description of the system and its objectives.

Application of EMAS Scheme to hospital sector requires, analysis of functional areas and their healthcare process, to find specific issues and suitable measures allowing fulfilment of common sustainability objectives, such as reduction of waste production and their hazard degree.

Environmental sustainability in the functional domain

Indoor environmental quality and indoor air quality are responsible for an high energy consumption, therefore, for an high pressure on environment. High energy consumption depends on the need to maintain controlled levels of indoor comfort. These levels could change according to the kind of medical activity and healthcare process. Indoor environmental quality is defined by thermal-hygrometric, visual and acoustic microclimate; indoor air quality is defined by ventilation and emission from building materials.

As well known, indoor comfort has a directly effect on building users; therefore it influences psychological and physical human abilities.

In the case of hospitals, indoor comfort is strictly related to health and safety of staff and patients. Many researches have investigated the role of physical environment in the healing process. According to them health is a state of complete physical, psychological and social well being; not only the absence of illness! (WHO). For instance, Psychosocially Supportive Design, is aimed to stimulate a mental process attracting human attention, in order to reduce stress and promote positive emotion. Elements of physical environment, in a positive meaning, such as clean air, natural lighting, sound and music, nature, and other elements such as colours, art and space conformation, became salutogenic factors, capable of promoting, maintaining, sustaining positive outcomes in healing process.

On the same assumption is bases l'EBD (Evidence Based Design) that address design and operation of building to support positive health outcomes in hospital through a growing collection of solution informed by research and practical knowledge (Hamilton, 2003).

Other researches investigated these theories on high-risk functional areas such as intensive care unit or surgery block. In a hospital of Pennsylvania, 12 patient rooms of the surgery block have been monitored in the period from 1972 to 1981. Six of them looked into an open area with trees, and other ones looked at a brick wall. Monitoring activity demonstrated that severity of operation, patient's profile and staff rigor, were the same but the analgesic quantity and the duration of healing process were reduced of 30% for patient in rooms with pleasing view (Ulrich, 1984).

These researches demonstrate the opportunity to treat functional areas in a diversified way, more appropriated to the kind of healthcare process.

Environmental sustainability in the technical domain

In relation to technical domain, hospitals are characterized by an high consumption of energy during the whole life cycle. In Italy, energy consumption of hospitals is three times higher than residential sector's one (Fasano, 2009).

According to a study conducted about Italian hospitals, the expense for energy is only 2% on the total management expense. The percentage is relatively low, so facility managers are not stimulated to take improvement measures. But, if considered par rapport to the national budget, the expense is 2 billion of Euros. Economic advantages resultant from improvement of energy efficiency has to be considered as a growing of resources available for quality of hospital, from indoor comfort to new medical equipments, for users and community wellness.

Hospitals are characterized also by an high consumption of resources, due to flexibility. This is required to allow growing in dimension or internal layout modification; in fact, the scientific and technological progress requires adaptation both of medical process and healthcare facilities.

Therefore, "flexibility" requires special attention on infill service life and its environmental impact; design has to be consciousness that infill level is made of cluster of technical component with different service life. Service life depends not only on technical reasons but also on rapid changing condition within healthcare sector. If service life of infill is short, the number of replacement, repair, refurbishment, etc, will be more frequently during hospital life cycle.

As a matter of fact the higher flexibility level required is, several will be the number of infill replacement and modification.

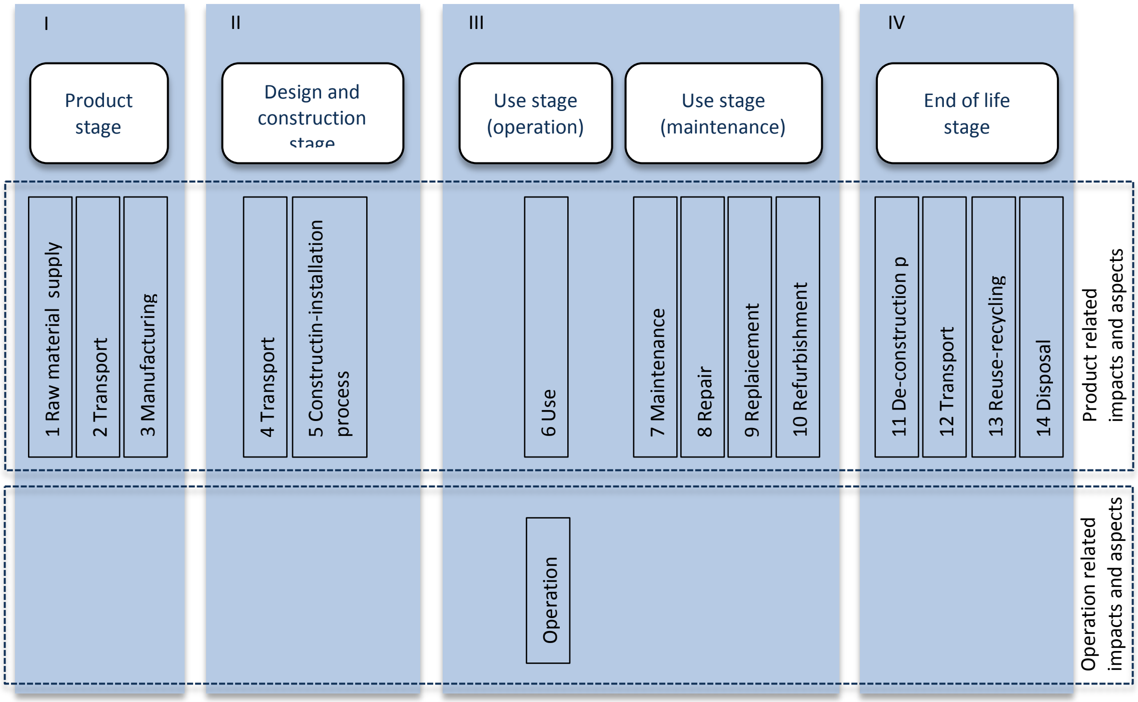

Figure 1: Building Life Cycle representation

Environmental sustainability of hospitals

After the previous description now is possible to give a definition of sustainable hospital:

> a system in which an environmentally engaged health care community is dedicated to the health of patients, workers, their communities and the global environment. A system where patients and staff interact in an healing environment that embraces safer building products, clean air, reduced toxins, safe working practices, energy and water efficiency, education and a commitment to public health demonstrated through waste volume and toxicity reduction (Hospital for healthy environment).

ENVIRONMETAL SUSTAINABILITY AND FLEXIBILITY IN HOSPITAL SYSTEMS.

Management and assessment tools should consider taking complexity of hospital systems. Complexity is something resulting from more parts, heterogeneous (Taylor, 2005). A complex system is characterized by numerous elements, different in quality (De Toni, Comello, 2005). This definition is appropriated to describe an hospital, characterized by a great heterogeneity. Hospitals, in fact, are resulting from more functional areas, each of which characterized by different technologic complexity and intensity of care.

In relation to environmental sustainability, is necessary to classify functional areas according to the kind of activity, and in function of technologic complexity and intensity of care: specific medical activity (high-care and high-care/high touch), activities such as hotel, office, industry activities.

Environmental impact, due to the operational activities, depends on the technologic complexity and intensity of care; at the same time the required flexibility level depends on the technologic complexity and intensity of care too. Therefore, flexibility level influences the environmental impact of hospitals in the whole life cycle. The proposed classification of the functional areas is in accordance with the one proposed by the Netherlands Board for Healthcare Institution (NBHI).

The open building theory as hypothesis of scenario for environmental impact assessment in operation stage.

Adopting the open building theory is possible to classify (in all functional areas) building components, furniture, fixture and fittings, according their estimated service life. The support subsystems have an estimated service life as long as the expected service life of healthcare facility; the infill subsystem have an estimated service life shorter than healthcare facility expected service life. For instance, if surgery department has an expected service life of 50 years, infill subsystems will be the ones characterized by a service life of 20 years, or less (such as, partitions, flooring, ceiling, etc.); support subsystems will be structure and plants (see table 2).

Table 1: Classification of functional areas in relationship to issue of environmental impact reduction during the life cycle.

Activity	Functional area
Specific Medical Activity	Reanimation, Emergency, Dialysis, Day surgery, Surgery, Partum Block, Radiotherapy, Radiology, Functional and endoscopic tests, Intensive care , Sub-intensive care
Activity like hotel	General Wards Cafeteria, Acceptance, Public services Storage, Dressing room, Cleaning service
Activity like office	Outpatients' department, Rehabilitation, Functional and endoscopic tests, Information service, Research and study service Medical and administrative office, Pharmacy, Technical services
Activity like industry	Histopathology and Anatomopathology (research), Transfusion center, Laboratories Blood bank, Sterilisation, Kitchen, Laundry

The estimated service life is defined as the service life that a building or an assembled system (part of works) would be expected to have in a set of specific in-use conditions, determined from reference service life data after taking into account any differences from the reference in use conditions [ISO/DIS 15686-1:2008].

Regard to infill subsystems, environmental impact assessment of operation stage has to include the impact due to maintenance, replacement and repair activities, and the impact due to production and installation of new components used in replacement and repair services. Environmental impact for replacement products shall include for:

- transportation;
- replacement process of replaced building component ;
- waste management for replaced products;
- end of life stage of the replaced building component.

In order to conduct an environmental life cycle assessment some hypotheses have to be done about flexibility of infill compared to flexibility of support. If the project is based on Open building strategy, the different scenarios will be identified in the logic of the project, oriented to design capacity of building to adapt itself to requirement change and in function of obsolescence level of its parts.

With improving of energy efficiency, and reduction of infill service life on the other hand, the impact due to replacement can became important.

So, is important controlling infill production impact and making hypotheses about future productive strategies. The most important impact indicators are: material and components embodied energy, and Global Warming Potential. These indicators can reach values comparable with ones related to energy management of hospital. It's important to reduce not only the impact due to replaced building components but also to replacement process; a project based on open building strategies should preview simplified and low impacting replacement process.

Environmental impact of flexibility: the case study of surgery block

Surgery block case study of San Giuseppe Hospital (Empoli, Italy) has been utilized as control environmental impact related to flexibility requirement. As well known, surgery block is characterized by an high level of technologic complexity and intensity of care, so by an high level of flexibility. Following, specificities of surgery block:

- in the process domain, medical waste production and emission of anaesthetic gas;
- in the functional domain, very clean area, and lower air temperature and humidity than in other functional areas;
- in the technical domain, specific building components and envelope such as ATU, anti X ray partition, etc, with the consequence of high resource consumption in the production phase.

Table 2: Synthesis of environmental requirements in technical domain. Gray colour indicates the infill subjected at rapidly modification/replacement. Environmental impact of this infill has been quantified through LCA tool

TECHNOGIC DOMAIN	Surgery block: systems and components environmental performance in the use stage			
	LIFE CYCLE ENVIRONMENTAL IMPACT	Support and Infill	Support	Structures
				External envelope
				Plants_main network
			Infill	Internal envelope (partitions, ceiling, flooring, doors, etc)
				ATU
				Plants_secondary network
				Terminal units
	Operational ENERGY EFFICIENCY	Building-system	Heating and cooling	
			Hot water	
			Lighting	
		Building automation and control	Medical equipments	
		Renewable source	Green Energy producted	
		Monitoring system	BMS Energy Meters	

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In the case study of surgery block the internal envelope is an infill subjected at rapidly modification/replacement, in particular: partition, ceiling, flooring and doors, of operating theatres and surgeons preparation rooms. It's not easy to preview expected service life of this infill, because it depends on scientific and technologic progress in medic field, not only on durability of components used. Is possible to assume a service life of 5-10 years for infill, with the hypothesis of 5 replacement; for the support a service life of 25-30 is reasonable. Assessment of environmental impact related to production stage can be conducted through current methodologies. The assessment is aimed to find low impacting components, to encourage manufactures, designers and managers to improvement of building's environmental performance.

Partition of operating theatre

Partitions of operating theatre have to guarantee a perfect air-proofness (higher pressure is requested). Partitions are usually prefabricated. Operating theatres of the case study have a pre-varnished stainless steel partition (total thickness 20 mm). Metal structure is made of horizontal guide in zinced steel, both on flooring and ceiling, horizontal intermediate guide in zinced plate, vertical guide in rectangular zinced tubular.

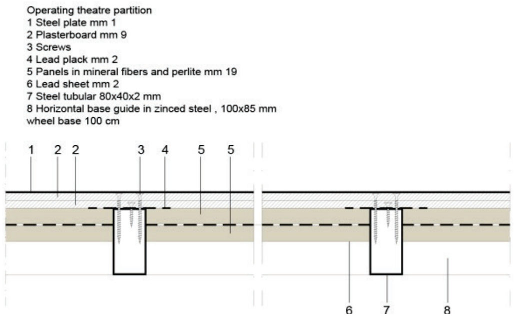


Figure 2: Partition of operating theatre (horizontal section).

Covering panels are composed of:

- stainless steel plate, thickness 1 mm ;
- internal rigidity elements in plasterboard, thickness 18 mm.
- Partitions have anti X ray protection made of a lead sheet (thickness 2 mm), located between two mineral fibres and perlite panels.

Other partitions

Other partitions are in plasterboard. Thickness and stratigraphy change according to delimitated functional unit. In particular, anti X ray protection is positioned for operating theatres and plaster room; high humidity-proofness plasterboard are utilised in surgeons preparation rooms.

Flooring

Flooring is in anti-static PVC (total thickness 2 cm)

Ceiling

Ceiling is composed by an air proofness pre-varnished zinced steel (600x600 mm panels).

Doors

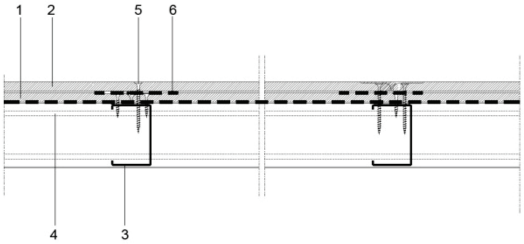
Installed doors are in sandwich panels, their finishes are in stainless steel plate, pre-varnished by epoxy resins varnish.

Insulation is composed of high density and rigid poliurethanic mousse. Following, 4 type of doors: the door 1, 1.4X2.1 m, with anti X ray protection, used between operating theatre and clean corridor, between operating theatre and plaster room; the door 1a, 1.4X2.1 m (no anti X ray protection) used between the plaster room and the clean corridor; the door 2, 0.9X2.1 m, with anti X ray protection, used between operating theatre and dirty corridor, between operating theatre and surgeon preparation room; the door 3, 0.8X2.1 m (no anti X ray protection), used between surgeons preparation room and clean corridor, between plaster room and dirty corridor.

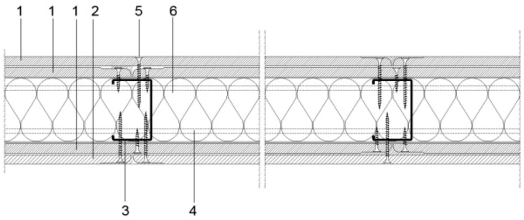
Methodology used for environmental impact assessment

Environmental impact of considered infill has been calculated according the Life Cycle methodology (LCA – Life Cycle Assessment), regulated by ISO 14040:2006. The LCA represent a scientific assessment methodology of energy and environmental loads, and potential impact associated to product/process/activity in the whole life cycle, from raw material supply to end of life (from Cradle to Grave).

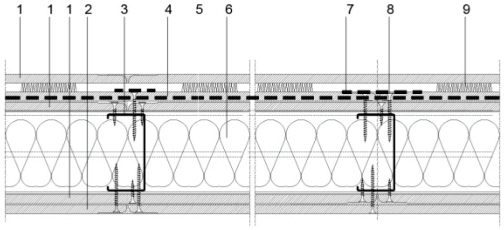
Partition A
1 Plasterboard with lead sheet of 2 mm, total tickness mm 12,5
2 Plasterboard humidity resistant mm 12,5
3 stell vertical framework, mm 75x50x0.6
4 Horizontal base guide in zinced steel, mm 75x40x0.6
5 Screws
6 Lead plack mm 2
wheel base 60 cm



Partition B
1 Plasterboard mm 12,5
2 Humidity resistant plasterboard mm 12,5
3 Vertical framework in steel , mm 75x50x0.6
4 Horizontal base guide in zinced stell, mm 75x40x0.6
5 Screws
6 Insulation in mineral wool
wheelbase 60 cm



Partition D
1 Plasterboard mm 12,5
2 Humidity resistant plasterboard mm 12,5
3 Vertical framework in steel, mm 100x50x0.6
4 Plasterboard with lead sheet of 2 mm, total thickness mm 12,5
5 Horizontal base guide in zinced steel, mm 100x40x0.6
6 Insulation in minaral wool mm 60
7 Lead plack mm 2
8 Screws
9 Glue
wheelbase 60 cm



Partition E
1 Plasterboard mm 12,5
2 Humidity reistant plasterboard mm 12,5
3 Vertical framework in steel, mm 75x50x0.6
4 Horizonal base guide in zinced steel, mm 75x40x0.6
5 Screws
wheelbase 60 cm

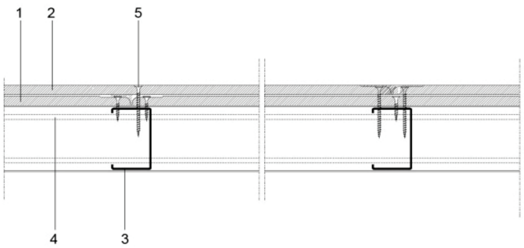


Figure 3: Example of other partitions in studied surgery block (horizontal section).

According to LCA methodology, an "input-output" analysis has been conducted in order to quantify resources allocated and emission production in the stage from cradle to gate, that means from raw material supply to the product production. Environmental profile has been calculated by Pre – SimaPro7.1.8 software. They are related to 1 sqm unit

Following, the data bank used: IDEMAT 2001, BUWAL 250, ETH-ESU and Ecoinvent. Impacts have been expressed through indicators used in environmental product declarations (EPD, regulated by ISO 14025) and proposed by CEN for environmental building evaluation: Photochemical Oxidation, Acidification, Eutrophication, Ozone Layer Depletion, Global Warming Potential, Non Renewable Fossil Energy. Following tables show results.

ENVIRONMENTAL IMPACT OF CEILING PRODUCTION STAGE		
Impact category	Unit	
ENVIRONMENTAL IMPACT OF 1 SMQ		
Acidification	kg SO2 eq	1.12E-01
Eutrophication	kg PO4 eq	6.40E-03
Global Warming Potential	kg CO2 eq	9.87E+00
Ozone Layer Depletion	Kg CFC-11 eq	3.03E-08
Photochemical Oxidation	kg C2H4	1.06E-02
Non Renewable, fossil	MJ eq	1.86E+02

ENVIRONMENTAL IMPACT OF OPERATING THEATRE PARTITION PRODUCTION STAGE		
Impact category	Unit	
ENVIRONMENTAL IMPACT OF 1 SMQ		
Acidification	kg SO2 eq	5.27E-01
Eutrophication	kg PO4 eq	2.92E-02
Global Warming Potential	kg CO2 eq	5.52E+01
Ozone Layer Depletion	Kg CFC-11 eq	1.19E-05
Photochemical Oxidation	kg C2H4	2.90E-02
Non Renewable, fossil	MJ eq	9.19E+02

ENVIRONMENTAL IMPACT OF FLOOR PRODUCTION STAGE		
Impact category	Unit	
ENVIRONMENTAL IMPACT OF 1 SMQ		
Acidification	kg SO2 eq	4.10E-02
Eutrophication	kg PO4 eq	3.61E-03
Global Warming Potential	kg CO2 eq	6.10E+00
Ozone Layer Depletion	Kg CFC-11 eq	0.00E+00
Photochemical Oxidation	kg C2H4	1.40E-03
Non Renewable, fossil	MJ eq	1.26E+02

ENVIRONMENTAL IMPACT OF PARTITION A,B,C,D PRODUCTION STAGE					
Impact cat.	Unit	PAR A	PAR B	PAR C	PAR D
ENVIRONMENTAL IMPACT OF 1 SMQ					
Acidification	kg SO2 eq	2.89E-01	1.11E-01	2.93E-01	3.62E-01
Eutrophication	kg PO4 eq	1.95E-02	1.48E-02	2.01E-02	2.92E-02
Global Warming Potential	kg CO2 eq	3.72E+01	2.61E+01	3.83E+01	5.36E+01
Ozone Layer Depletion	Kg CFC-11 eq	1.14E-05	2.36E-06	1.15E-05	1.28E-05
Photochemical Oxidation	kg C2H4	1.37E-02	6.78E-03	1.39E-02	1.76E-02
Non Renewable, fossil	MJ eq	6.13E+02	4.39E+02	6.31E+02	8.91E+02

ENVIRONMENTAL IMPACT OF PARTITION E,F,G,H PRODUCTION STAGE					
Impact category	Unit	PAR E	PAR F	PAR G	PAR H
ENVIRONMENTAL IMPACT OF 1 SMQ					
Acidification	kg SO2 eq	5.30-02	1.22E-01	3.66E-01	1.13E-01
Eutrophication	kg PO4 eq	6.65E-03	1.57E-02	2.97E-02	1.50E-02
Global Warming Potential	kg CO2 eq	1.20E+01	2.75E+01	5.47E+01	2.65E+01
Ozone Layer Depletion	Kg CFC-11 eq	1.06E-06	2.41E-06	1.30E-05	2.41E-06
Photochemical Oxidation	kg C2H4	3.98E-03	7.90E-03	1.78E-02	6.84E-03
Non Renewable, fossil	MJ eq	2.02E+02	4.64E+02	9.08E+02	4.45E+02

ENVIRONMENTAL IMPACT OF DOOR 1,1a,2,3 PRODUCTION STAGE					
Impact category	Unit	DOOR 1	DOOR 1a	DOOR 2	DOOR 3
ENVIRONMENTAL IMPACT OF WHOLE COMPONENT					
Acidification	kg SO2 eq	2.68E+00	1.61E+00	1.72E+00	9.30E+01
Eutrophication	kg PO4 eq	1.23E-01	6.36E-02	7.90E-02	3.66E-02
Global Warming Potential	kg CO2 eq	2.30E+02	1.13E+02	1.48E+02	6.52E+01
Ozone Layer Depletion	Kg CFC-11 eq	4.69E-05	3.14E-07	3.01E-05	1.81E-07
Photochemical Oxidation	kg C2H4	1.47E-01	1.03E-01	9.45E-01	5.95E-01
Non Renewable, fossil	MJ eq	3.89E+03	2.00E+03	2.50E+03	1.15E+03

According to results high environmental impact comes from anti X ray protection infill. According to GWP graphic (Global Warming Potential), partition of operating theatre (OP) is in absolute the more impacting infill, followed by partition G and D. Partition of operating theatre has been compared with a glass-steel office partition and a plasterboard common partition (see figure --), in order to do results more palpable.

The same result has been obtained for the whole surgery block. Major contribute to environmental impact is due to anti X ray partition. Besides, flooring and other partitions contribute is relatively low.

CONCLUSIONS

In conclusion, environmental sustainability evaluation tools have to be adapted to main hospital features:

strong relationship between building and activity/process and,
heterogeneity.

Integration of process, functional and technical domain in evaluation tools is needed for the environmental sustainability evaluation. This paper suggests the "crossing" of the actual state of the art that separate environmental design and management tools of hospital building (such as ecolabel for hospital buildings) from environmental management tools of hospital organizations (such as EMAS scheme).

In relation to technical domain, the weighting of impact reduction measures is significant, it should be based on infill quantity and its expected service life.

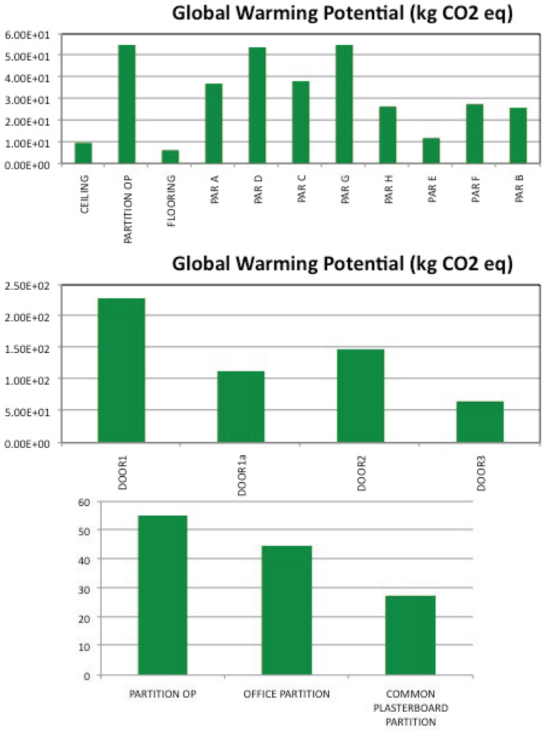


Figure 4: GWP of studied infill (top, bottom on the left) and comparison of operating theatre partitions with a glass-steel office partition and a plasterboard common partition (bottom on the right). Results are related to 1 sqm (regard to partitions, ceiling and flooring) and to a complete element (regard to doors).

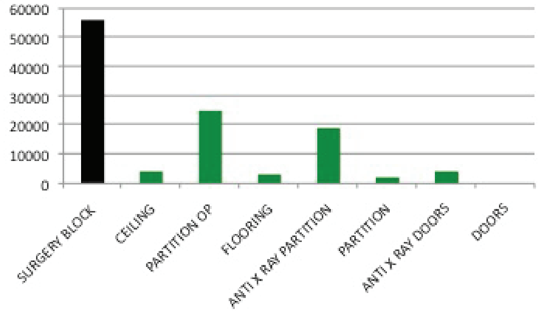


Figure 5: GWP related to the total quantity of studied infill in surgery block.

Table 3: Weighting hypothesis of environmental impact reduction measures in function of and quantity and expected service life. The dark indicates the major weight.

	Expected Service life (s, expressed in years)			
Quantity of component/Total quantity of components in the same category	Infill		Support	
	10 < s < 20	s < 10	s > 50	20 < s < 50
Low	░	░	░	░
Medium	▒	▓	▒	▓
High	▓	█	▓	█

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