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Window Design Strategies for Environmentally Friendly and Energy Efficient Patient Rooms: A Case Study in the Belgian Context

N Eisazadeh[1], K Allacker[1] and F De Troyer[1]

[1] Department of Architecture, KU Leuven, Kasteelpark Arenberg 1, 3001 Leuven, Belgium

nazanin.eisazadeh@kuleuven.be

Abstract. With the increasing awareness of sustainable design "operational energy use", "life cycle environmental impact" and "comfort" are becoming key considerations for design decisions. These three aspects are usually not explored in an integrated way in the early design stage. During this stage however, most far-reaching design decisions are made and the greatest potential to achieve sustainable building designs in a cost-efficient way exists. Hence energy efficiency, environmental performance and comfort should be considered as a fundamental part of early design stage decisions. This paper investigates the influence of various patient room design options on the energy cost, life cycle environmental impact and daylighting. The design parameters investigated are the room geometry, type of glazing and WWR (Window-to-Wall Ratio). The analysis is performed for a case study in Belgium, more specifically a patient room in a hospital design. The existing design is taken as a baseline scenario and via parametric analysis, the influence of alternative design strategies is analysed. Based on the comparative analysis, the paper discusses potential design strategies that allow for energy efficient and environmentally-friendly patient rooms that fulfil comfort requirements for patients.

1. Introduction

Hospitals are considered one of the most energy demanding building types that produce high amounts of emissions due to their constant operation, high flow of people, and intensive HVAC (Heating, Ventilation and Air Conditioning) requirements. In Europe the healthcare sector is responsible for more than 5 % of the greenhouse gas emissions [1], hence strategies are necessary to improve the energy performance and reduce the environmental impacts while still maintaining a comfortable indoor environment for patients.

Windows influence the heat flow, solar gains and aesthetics of buildings to an important extent, and provide access to daylight and view to the outside. To avoid high energy and resource consumption, to reduce the environmental impact and to increase the quality of the space, selecting the appropriate size and type of window system based on the design geometry, climate, building function, orientation and occupants' needs are a fundamental part of early design stage decisions and are difficult to change later on. However, the influence of alternative design options on the building performance is usually not explored in the early design stage. Even though most building design decisions are made during this stage and the greatest potential to achieve sustainable building designs exists during that phase.

Literature review shows that only a limited number of studies address the impact of patient room design options on energy efficiency and daylighting [2] [3] [4] and there appears to be no study focusing on the influence of patient room design options on the environmental performance. There is hence a need for an integrated performance analysis of patient room design and the associated design parameters impact on energy consumption, environmental performance and daylighting.

The aim of this study is to determine the influence of various patient room design options on the energy cost, life cycle environmental impact and daylighting. The effect of several components is investigated, such as the room dimensions, type of glazing, WWR (Window-to-Wall Ratio) and WFR (Window-to-Floor Ratio). Different design alternatives are explored through parametric modelling. The methodology combines dynamic energy simulations and daylight analysis and integrates these in the LCA (Life Cycle Assessment) study of the patient rooms in the Belgian context.

2. Methodology

This paper investigates the effect of patient room dimensions, glazing type, WWR and WFR on the annual energy cost, life cycle environmental impact and daylighting performance. The alternative design options are evaluated in four steps. In a first step, the energy cost for heating, cooling, and artificial lighting obtained from the parametric design model are compared and the design options with lowest energy cost and higher access to daylight are identified. In a next step, the life cycle environmental impact of the selected design options is calculated and analysed. A third step assesses the daylighting performance at the patient's position. In a final step, the design parameters that have the highest influence on patient room overall performance are identified.

The parametric patient room is modelled in Grasshopper, which is a plugin for Rhinoceros (3D modelling tool). Detailed patient room simulation parameters such as construction types, materials, schedules are assigned to the model using Ladybug & Honeybee components for Grasshopper. Parametric simulations are performed using the Grasshopper plugin Colibri and for the energy and daylighting analysis Ladybug & Honeybee are used to interface with the simulation engines EnergyPlus, Radiance and Daysim. For the LCA study the "MMG+_KU Leuven" tool is used which is an Excel-based tool developed at the research division of Architectural Engineering at KU Leuven in collaboration with VITO (Vlaamse Instelling Voor Technologisch Onderzoek) and BBRI (Belgian Building Research Institute).

2.1. Simulation model description

The width and the depth of the parametric model range from 3.60 to 4.50 m and 3.90 to 6.00 m respectively with increments of 0.3 m. This is based on standard dimensions for a one-bed patient room. The height of the model is fixed at 3.0 m. For each patient room six glazing types and seven WWR are analysed. The WWR values range from 20 % to 80 %, with 10% increments. The parameters of the model and their minimum and maximum values are shown in table 1. Only the floor area occupied by the patient is taken into account in the parametric model dimensions, the service area, including the bathroom, is not considered (see Figure 1).

Glazing with different g-values, visible transmittance (Tvis) and U-values are considered to investigate the role of the glazing characteristics on the energy loads, lighting energy use and daylighting. Table 2 lists the key properties of the glazing types adopted in this study and Figure 2 shows the position of the coating within the glazing. The double/triple glazing consists of 4 or 6 mm glass panes and 15 or 16 mm cavity filled with gas (90% argon). The Berkeley lab WINDOW 7.6 software is used to determine the thermal and optical characteristics of the glazing. The uncoated glazing acts as benchmark for understanding the influence of the coating. The uncoated glazing however does not comply with new building construction standards in Belgium as the U-value of the window should not exceed 1.50 (W/m^{2}K). The patient room has one external wall (U-value = 0.22 W/m^{2}K) with a single window facing south; all other surfaces are assumed adiabatic and the properties of the envelope are according to the Belgian standards for new buildings. The patient room is located on the second floor; no external obstruction is taken into account. EnergyPlus weather data for Brussels is used for the simulations.

2.2. Energy analysis

The annual energy use and cost for heating, cooling and lighting are calculated using EnergyPlus and taking into account the solar and thermal properties of the glazing with detailed layer by layer glazing system modelling. Using a lighting schedule generated through the Radiance and Daysim software by Honeybee component for annual daylight simulation, a daylight-linked lighting control is employed. The illumination level set point for activating lighting is 300 lux and the lighting sensor is located in the middle of the room at 1.10 m above floor level. If the illumination levels drop below this threshold (checked on an hourly basis), lighting is switched on.

Space heating and cooling set point temperatures are assumed to be 21°C and 24°C respectively, mechanical ventilation is set to 2.00 (ac/h) and infiltration is considered 0.20 (ac/h). These assumptions are in line with standards provided for patient rooms. Mechanical ventilation is modelled with heating and cooling using the EnergyPlus Ideal loads system; the effects of heat recovery and economiser are included. For heating a global system efficiency of 0.85 is considered and for cooling a CoP (Coefficient of Performance) of 1.80. Natural gas (heating) and electricity (cooling and lighting) prices (€/kWh) are based on the Belgian market prices in 2017.

Table1. Parametric variables values

Variables	Minimum	Maximum	Step
Width of the room	3.60 m	4.50 m	0.30 m
Depth of the room	3.90 m	6.00 m	0.30 m
WWR	20 %	80 %	10 %
WFR*	10 %	61 %	-

* Derived from parameters above

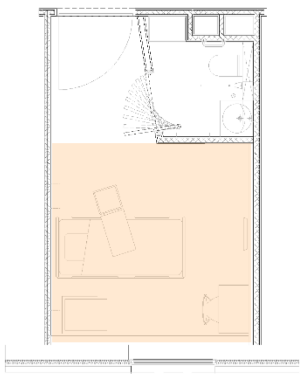

Figure 1. The patient room area taken into account for parametric model dimension

Table 2. Glazing characteristics

GLZ [Tvis*/g-value]	Configuration	Coating features	U-value (W/m^{2}K)
GLZ [0.82/0.80]	4-16-4	No coating	2.50
GLZ [0.82/0.64]	4-16-4	Thermal insulation + High (light transmission + g-value)	1.10
GLZ [0.73/0.39]	6-16-4	Solar control + Thermal insulation	1.10
GLZ [0.76/0.74]	4-15-4-15-4	No coating	1.70
GLZ [0.75/0.53]	4-15-4-15-4	Thermal insulation + High (light transmission + g-value)	0.60
GLZ [0.47/0.25]	6-15-4-15-4	Solar control + Thermal insulation	0.90

* Visible transmittance

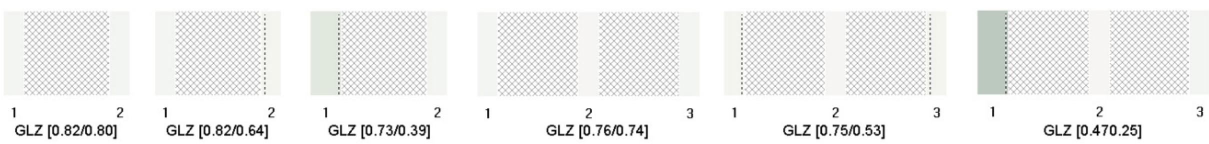

Figure 2. Coating position within glazing; 1- Outer glass pane
Dotted line: position of coating(s)

2.3. LCA study

The "MMG+_KU Leuven" tool is used for the LCA. This tool is based on the MMG method: the national method in Belgium to quantify the environmental performance of building elements. The LCIA (Life Cycle Impact Assessment) method in the MMG method combines the environmental impact indicators CEN and CEN+ [5]. The CEN indicators include global warming, ozone depletion, acidification, eutrophication, photochemical ozone creation, abiotic depletion resources-elements, abiotic depletion-fossil fuels and the CEN+ indicators cover human toxicity, particulate matter formation, ionising radiation: human health, ecotoxicity, water scarcity, land occupation and land transformation.

For each impact category the results are expressed as characterised results (equivalents) and as external environmental costs (monetary values, €). For the latter, the characterization values for each environmental indicator are multiplied by a monetisation factor. This factor reflects the extent of the potential damage to humans and/or the environment, expressed in a financial amount for the purpose of avoiding potential damage or compensating elsewhere or settling any damage incurred. These euro based figures express the environmental damage that is not incorporated in the present market prices but are passed on to society through e.g. sickness and damage to biodiversity [6]. Further details on the method can be found in De Nocker and De Backer [7].

The environmental impacts associated with each glazing type are assembled based on the EPD (Environmental Product Declaration) and data obtained from the AGC (Asahi Glass Co., Ltd) Glass Europe. This is integrated into the MMG+_KU Leuven tool. To calculate and study the life cycle environmental impact of patient room designs, the selected design options are modelled in the MMG+_KU Leuven tool also incorporating the energy use from EnergyPlus. Further details about the procedure is provided in Figure 3.

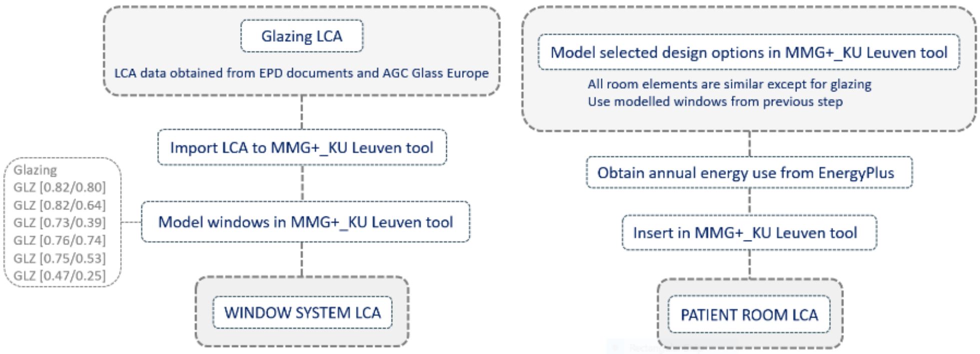

Figure 3. LCA method

2.4. Daylighting analysis

In this study climate-based daylight modelling is used, which provides daylight predictions under realistic sun and sky conditions derived from weather data. Daylighting analyses are conducted through Honeybee which uses the Radiance based daylighting analysis tool Daysim. The output from Daysim is a data file containing the annual illuminance values for the analysis points in the room.

DA (Daylight Autonomy), $sDA_{300/50\%}$ (spatial Daylight Autonomy), and UDI (Useful Daylight Illuminance) metrics are used to assess the daylighting performance and visual comfort. DA is defined as a percentage of annual considered daytime hours that a given point in a space is above a specified illumination threshold. The $sDA_{300/50\%}$ describes the percentage of an analysed area that meets a target illuminance – usually 300 lux – for at least 50 % of the annual occupied hours. As the illuminance necessary for simple examination and reading is 300 lux, this value is analysed for the reference point to ensure sufficient daylight at the patient's position. $UDI_{100\text{-}2000lux}$ determines when daylighting levels are 'useful' for the occupants and $UDI_{>2000lux}$ presents the times when it's too bright and an oversupply of daylight could lead to visual and/or thermal discomfort; both the threshold illuminance of $UDI_{100\text{-}2000lux}$ and $UDI_{>2000lux}$ are studied [8] [9].

The daylighting simulation is performed from 7 AM to 9 PM, as during this period of the day the patients need daylight/lighting. The spatial distribution of the daylight target is evaluated for a grid of sensor points with a spacing of 0.3 m distributed over the surface of the patient's eye level plane in fowler's position (patient sitting in a semi-upright position in bed) at 1.10 m above floor level, also including the reference point (sensor) which is located at patient's eye position. The walls, ceiling and floor reflectance are assumed to be 50 %, 80 % and 20 % respectively.

			Width*Depth	WWR (%)													
				20		30		40		50		60		70		80	
Glz[0.82/0.80]	Energy cost (€)	sDA (%) / WFR (%)	3.60*3.90 (m)	93	28 / 15	106	42 / 23	119	53 / 30	136	62 / 38	152	71 / 46	169	80 / 54	186	96 / 61
	Energy cost (€)	sDA (%) / WFR (%)	3.60*4.20 (m)	105	26 / 14	114	38 / 21	127	49 / 28	142	56 / 36	158	65 / 43	176	71 / 50	193	78 / 58
	Energy cost (€)	sDA (%) / WFR (%)	3.90*3.90 (m)	106	26 / 15	117	41 / 23	132	55 / 31	148	63 / 38	166	71 / 46	184	87 / 54	203	97 / 61
	Energy cost (€)	sDA (%) / WFR (%)	4.20*3.90 (m)	107	26 / 15	122	40 / 23	138	55 / 31	157	63 / 38	176	72 / 46	196	88 / 54	217	99 / 61

			Width*Depth	WWR (%)													
				20		30		40		50		60		70		80	
Glz[0.76/0.74]	Energy cost (€)	sDA (%) / WFR (%)	3.60*3.90 (m)	87	24 / 15	95	40 / 23	106	51 / 30	118	60 / 38	131	68 / 46	145	76 / 54	159	90 / 61
	Energy cost (€)	sDA (%) / WFR (%)	3.60*4.20 (m)	99	23 / 14	104	37 / 21	113	48 / 28	125	55 / 36	137	62 / 43	151	67 / 50	165	74 / 58
	Energy cost (€)	sDA (%) / WFR (%)	3.60*4.50 (m)	107	20 / 13	112	34 / 20	120	44 / 27	130	51 / 33	143	57 / 40	155	63 / 47	170	68 / 53
	Energy cost (€)	sDA (%) / WFR (%)	3.90*3.90 (m)	100	25 / 15	107	38 / 23	117	51 / 31	130	61 / 38	143	69 / 46	158	78 / 54	173	94 / 61

Figure 4. Design options with uncoated glazing (upper table = double glazing, lower table = triple glazing)

3. Result and discussion

3.1. Energy analysis

The combinations of the various parameters result in 224 options for each glazing type. For every option, the yearly energy cost and sDA are calculated. As expected in Belgium, heating represents the highest share in the energy use, followed by lighting and cooling loads or vice versa based on the design option. It should be noted that the price of electricity for one kWh (cooling + lighting) is approximately four times more than the price per kWh of natural gas (heating) in Belgium.

The design alternatives with the lower energy costs and higher sDA have been identified and are presented in figures 4 and 5. In order to facilitate the selection of options for the next steps, the best design option with the lowest energy cost and the minimum sDA of 50 % for non-coated double glazing is identified and acts as a benchmark. As can be seen in Figure 4 the energy cost of the selected option is 119 €; For all design alternatives, the options with the maximum energy cost of 120 € and sDA ≥ 50 % are highlighted in a light grey tone. The darkest grey cell in all figures represents the best design option with the minimum energy cost and maximum daylight based on the tested criteria.

Figure 4 shows that the design options that fulfil the above mentioned criteria are very limited when using uncoated glazing. The best performing option is a room with 3.60 m width and 3.90 m depth and 40% WWR (30% WFR). Figure 5 shows that for double pane coated glazing the number of design options that fit the criteria increases significantly for options using glazing with a lower g-value; incorporating this type of glazing allows for higher WWRs and WFRs. The best performing option for double glazing are a 3.60 m x 3.90 m (width x depth) room with 40% WWR (30% WFR). When using triple glazing, a 3.60 m x 3.90 m (width x depth) room is again the preferred choice. However, the room dimension and WWR range differs considerably for the two types of glazing. The number of design options that fit the criteria for triple glazing with higher light transmission increases significantly due to the fact that more options attain the target criterion of sDA ≥ 50 %.

It is observed that the best performing option applicable to almost all cases is a 3.60 m x 3.90 (width x depth) room with 40% WWR and 30% WFR. As triple pane solar control coated glazing

(GLZ [0.47/0.25]) does not comply with the criterion sDA ≥ 50 %, for the next steps only for this type of glazing two options are selected; 1. the same option as all other glazing types, 2. the best performing option that fits within the criteria with the same dimensions (see Figure 5). Table 3 shows the parameters associated with the selected options.

Table 3. Selected design options

Design options	Glazing type	Width*Depth	WWR	WFR
Case 1	GLZ [0.82/0.80]	3.60*3.90 (m)	40%	30%
Case 2	GLZ [0.82/0.64]	3.60*3.90 (m)	40%	30%
Case 3	GLZ [0.73/0.39]	3.60*3.90 (m)	40%	30%
Case 4	GLZ [0.76/0.74]	3.60*3.90 (m)	40%	30%
Case 5	GLZ [0.75/0.53]	3.60*3.90 (m)	40%	30%
Case 6	GLZ [0.47/0.25]	3.60*3.90 (m)	40%	30%
Case 7	GLZ [0.47/0.25]	3.60*3.90 (m)	60%	46%

Glz[0.82/0.64]

Width*Depth		WWR (%) 20	30	40	50	60	70	80
3.60*3.90 (m)	Energy cost (€)	81	87	95	105	115	126	137
	sDA (%)	27	42	53	62	71	80	96
	WFR (%)	15	23	30	38	46	54	61
3.60*4.20 (m)	Energy cost (€)	92	96	103	112	121	132	144
	sDA (%)	26	38	49	56	65	71	78
	WFR (%)	14	21	28	36	43	50	58
3.60*4.50 (m)	Energy cost (€)	101	103	109	118	127	137	149
	sDA (%)	22	37	47	53	61	65	71
	WFR (%)	13	20	27	33	40	47	53
3.90*3.90 (m)	Energy cost (€)	93	98	105	116	126	138	150
	sDA (%)	26	41	54	62	71	87	97
	WFR (%)	15	23	31	38	46	54	61
3.90*4.20 (m)	Energy cost (€)	99	103	110	121	131	143	155
	sDA (%)	24	38	50	57	66	73	83
	WFR (%)	14	21	28	36	43	50	57
4.20*3.90 (m)	Energy cost (€)	93	100	110	122	133	146	160
	sDA (%)	26	40	54	63	72	88	97
	WFR (%)	15	23	31	38	46	54	61
4.20*4.20 (m)	Energy cost (€)	104	110	118	129	141	153	166
	sDA (%)	24	37	50	58	66	74	89
	WFR (%)	14	21	28	36	43	50	57

Glz[0.73/0.39]

Width*Depth		WWR (%) 20	30	40	50	60	70	80
3.60*3.90 (m)	Energy cost (€)	77	80	85	91	99	106	115
	sDA (%)	24	37	50	57	65	72	82
	WFR (%)	15	23	30	38	46	54	61
3.60*4.20 (m)	Energy cost (€)	90	89	93	99	105	112	121
	sDA (%)	22	34	47	52	60	65	72
	WFR (%)	14	21	28	36	43	50	58
3.60*4.50 (m)	Energy cost (€)	97	98	100	105	110	118	125
	sDA (%)	20	31	43	49	55	60	66
	WFR (%)	13	20	27	33	40	47	53
3.90*3.90 (m)	Energy cost (€)	89	91	96	101	109	117	126
	sDA (%)	24	37	49	58	66	72	88
	WFR (%)	15	23	31	38	46	54	61
3.90*4.20 (m)	Energy cost (€)	95	96	101	107	114	121	130
	sDA (%)	22	34	46	53	59	66	74
	WFR (%)	14	21	28	36	43	50	57
4.20*3.90 (m)	Energy cost (€)	89	92	99	106	115	124	133
	sDA (%)	24	37	49	59	68	76	92
	WFR (%)	15	23	31	38	46	54	61
4.20*4.20 (m)	Energy cost (€)	101	103	107	114	121	130	140
	sDA (%)	22	34	44	54	61	67	75
	WFR (%)	14	21	28	36	43	50	57

Glz[0.75/0.53]

Width*Depth		WWR (%) 20	30	40	50	60	70	80
3.60*3.90 (m)	Energy cost (€)	75	78	81	86	93	99	107
	sDA (%)	24	40	51	59	67	73	87
	WFR (%)	15	23	30	38	46	54	61
3.60*4.20 (m)	Energy cost (€)	86	86	88	93	99	105	112
	sDA (%)	22	37	47	55	62	67	74
	WFR (%)	14	21	28	36	43	50	58
3.60*4.50 (m)	Energy cost (€)	93	94	95	99	105	111	118
	sDA (%)	20	34	43	50	57	62	68
	WFR (%)	13	20	27	33	40	47	53
3.60*4.80 (m)	Energy cost (€)	100	100	100	104	109	115	122
	sDA (%)	19	30	41	47	53	58	63
	WFR (%)	13	19	25	31	38	44	50
3.90*3.90 (m)	Energy cost (€)	87	87	90	96	102	109	117
	sDA (%)	25	37	50	59	69	78	92
	WFR (%)	15	23	31	38	46	54	61
3.90*4.20 (m)	Energy cost (€)	92	92	95	101	106	114	122
	sDA (%)	24	35	47	54	63	69	75
	WFR (%)	14	21	28	36	43	50	57
4.20*3.90 (m)	Energy cost (€)	86	89	93	100	108	116	124
	sDA (%)	24	37	51	61	69	81	94
	WFR (%)	15	23	31	38	46	54	61
4.20*4.20 (m)	Energy cost (€)	98	98	102	108	114	123	131
	sDA (%)	23	34	47	56	64	72	79
	WFR (%)	14	21	28	36	43	50	57

Glz[0.47/0.25]

Width*Depth		WWR (%) 20	30	40	50	60	70	80
3.60*3.90 (m)	Energy cost (€)	81	80	82	86	90	95	102
	sDA (%)	17	24	32	43	50	56	60
	WFR (%)	15	23	30	38	46	54	61
3.60*4.20 (m)	Energy cost (€)	93	91	91	95	98	103	108
	sDA (%)	15	23	30	40	45	51	55
	WFR (%)	14	21	28	36	43	50	58
3.90*3.90 (m)	Energy cost (€)	93	92	97	97	100	106	112
	sDA (%)	17	25	42	42	50	55	61
	WFR (%)	15	23	31	38	46	54	61
3.90*4.20 (m)	Energy cost (€)	99	97	98	101	105	111	116
	sDA (%)	15	23	30	39	47	51	57
	WFR (%)	14	21	28	36	43	50	57
4.20*3.90 (m)	Energy cost (€)	92	92	94	100	105	111	117
	sDA (%)	17	24	33	42	51	54	63
	WFR (%)	15	23	31	38	46	54	61
4.20*4.20 (m)	Energy cost (€)	105	104	104	108	113	119	125
	sDA (%)	15	22	30	38	47	50	57
	WFR (%)	14	21	28	36	43	50	57

Figure 5. Design options with coated glazing
(upper tables = double glazing, lower tables = triple glazing)

3.2. *LCA study*

In this step, the environmental performance of the selected design options from the previous step is evaluated. The results of the LCA study show that Case 1, Case 4 and Case 7 display the highest life cycle environmental impacts among the analysed options. In Case 1 and Case 4 with uncoated glazing this is due to higher energy use for space heating and cooling. For Case 7 with triple pane coated glazing this is due to the impacts associated with glazing as this case has the highest amount of float glass and WWR. As can be seen in Figure 6, the four remaining cases with coated glazing show a similar performance. However, Case 5 with the lowest energy use performs slightly better. The results indicate that global warming has the highest impact contribution in all cases. Seen the uncertainties inherent to the LCIA, it is not possible to identify the preferred option between the two better performing cases – Case 3 and Case 5 – as the differences are very small (< 2 %).

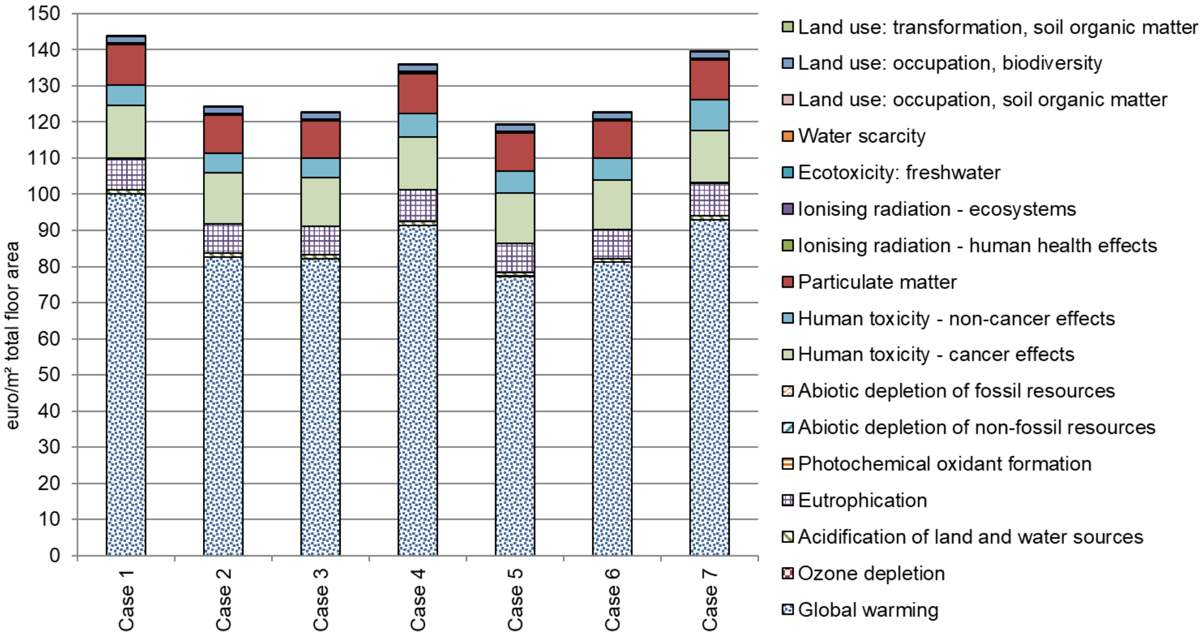

Figure 6. Environmental impact of patient room design options

3.3. Daylighting analysis

As can be seen in table 4, almost all selected cases show a quite uniform performance with 55–59 % DA at the selected reference point. The results show that the DA value at the patient's position in Case 6 with GLZ [0.47/0.25] is about 15 % lower compared to the other cases with higher light transmission glazing but still receives 48 % DA; which shows that 48 % of the year the target illuminance of 300 lux is met at the reference point with daylight alone. Moreover, this case has the highest percentage of useful daylight illuminance compared to other cases and still maintains an annual average illuminance of 416 lux at the patient's position. The results also indicate that compared to other cases this case displays ca 50 % lower annual illuminance values over 2000 lux which significantly reduces the probability of visual discomfort.

Table 4. Daylight at patient's position

Design option	DA	Ave-Illum	$UDI_{>2000lux}$	$UDI_{100\text{-}2000lux}$
Case 1	59%	766 lux	14%	56%
Case 2	59%	755 lux	13%	56%
Case 3	56%	658 lux	11%	58%
Case 4	58%	707 lux	12%	57%
Case 5	57%	691 lux	12%	57%
Case 6	48%	416 lux	6%	59%
Case 7	55%	623 lux	12%	57%

Figure 7 shows the annual hourly illuminance map at the patient's position ($UDI_{100\text{-}2000lux}$). The cases with the highest and lowest light transmission coated glazing are presented. As can be seen, the hourly illuminance values of minimum 2000 lux – shown in red – are more frequent for the case with high light transmission glazing which can lead to visual discomfort.

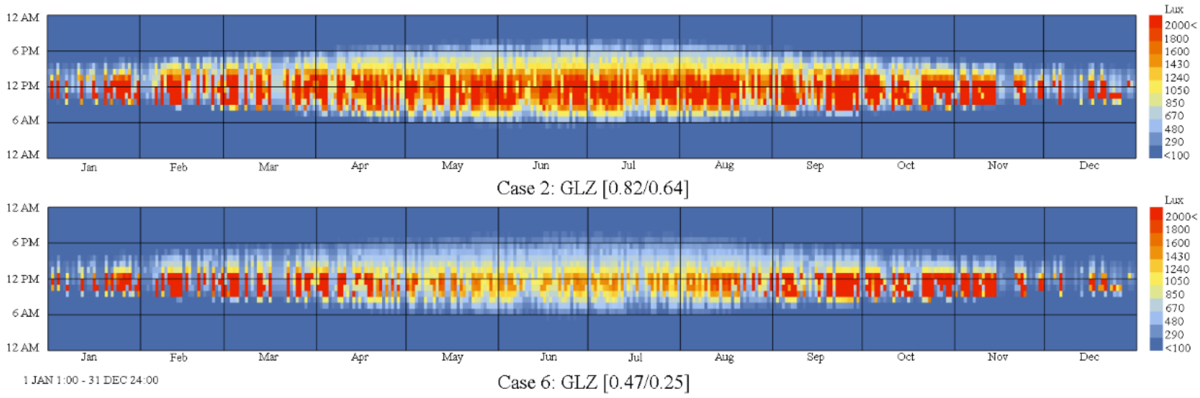

Figure 7. Annual hourly illuminance map at patient's position
(top: highest and bottom: lowest light transmission coated glazing)

4. Conclusion

The outcomes of this study revealed that the glazing characteristic have a major impact on the design performance and hence should be carefully selected during the design process. The results furthermore emphasis the need for a careful consideration of the window configuration and size in relation to the patient room design. The results moreover highlight the fact that the designs with glazing with a light transmission of 0.73–0.75 and a g-value of 0.39–0.53 show a wider range of accepted WWRs and room dimensions with lower energy costs. The design which incorporates this glazing characteristics (Case 5) shows the best overall performance of all studied cases. The influence of these glazing characteristics on visual comfort needs further investigation as the number of times that oversupply of daylight occurs at patient position are fairly high (12% $UDI_{>2000lux}$). However, the design with lower light transmission glazing (Case 6) shows a lower risk for visual discomfort. The study moreover revealed that the daylighting analysis metric influences the results especially for the designs with low light transmission glazing. As illustrated in Case 6, the sDA for the analysed area (patient's eye level plane) is 32 % while the sensor placed at the patient's eye position records 48 % DA. This is an important learning, especially for patient rooms (e.g. for bedridden patients) where adequate daylight at a specific point is important. Finally, the results indicate that design options with coated glazing have lower life cycle environmental impacts compared to options using non-coated glazing with similar WWR due to the reduction of the energy use which mainly influences the CO_2 emissions.

It can be concluded that focusing on individual aspects during the design process is not sufficient to get a correct insight in the building performance and an integrated approach is required. A parametric study considering the effect of different metrics (energy use, environmental costs, sDA, DA and UDI) on patient room design options (width/depth ratio, WWR, glazing types) can support architects in understanding the cross effects. Including this in a global evaluation (functional use of space, views to outside environment, reactions upon glare etc.) remains an important design challenge in each project.

List of Abbreviations

CoP	Coefficient of Performance
DA	Daylight Autonomy
EPD	Environmental Product Declaration
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
sDA	spatial Daylight Autonomy
Tvis	visible Transmittance
UDI	Useful Daylight Illuminance
WFR	Window-to-Floor Ratio
WWR	Window-to-Wall Ratio

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