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ScienceDirect

Energy Procedia 148 (2018) 1151–1158

Energy Procedia

www.elsevier.com/locate/procedia

73rd Conference of the Italian Thermal Machines Engineering Association (ATI 2018),
12–14 September 2018, Pisa, Italy

Energy savings in hospital patient rooms: the role of windows size and glazing properties

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Abstract

Large windows with increased exposure to daylight have strong positive effects on the well-being of building occupants and can provide energy savings when appropriate glazing specifications are employed.

The work evaluates the impact of different window sizes and glazing on heating and cooling energy needs in a hospital patient room, in order to investigate the energy savings achievable by adopting wider openings and to identify the most effective glazing types.

Simulations have been conducted for different commercially available glazing systems. The authors analyzed the energy performance of a base case window with 25% Window-to-Wall Ratio (WWR) and of a wall-to-ceiling window with 77% WWR, in rooms facing the four different orientations and located in Bologna, Italy. Results show that the adoption of wider windows with appropriate glazing can lower the heating and cooling energy demand.

Keywords: energy needs; hospital patient rooms; Window-to-Wall Ratio (WWR); glazing specifications; comfort; dynamic building energy simulations; TRNSYS

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10.1016/j.egypro.2018.08.027

1. Introduction

Hospital patient rooms, operating 24 hours per day year-round, require extremely high demands for space heating and cooling, since they need high ventilation rates and strict requirements for microclimatic control [1]. Given their typical location along the building perimeter to ensure daylight and views, patient rooms are among the hospital spaces with the highest percentage of external surface. This aspect contributes to high energy consumption, further increased with the age of the building envelope. For a comprehensive understanding of the latter observation, it is helpful to underline that in Italy, as well as in the rest of Europe, about 60% of the healthcare facilities were built before 1980 [2-3].

Besides accounting for the most fragile part of the envelope, window sizing has always been a critical issue in architectural design, due to the negative impact that windows have on the building heating and cooling needs. For this reason, large openings are usually avoided. However, wider fenestration systems, with appropriate low-emission coatings, could reduce both thermal transmission losses in winter and solar gains in summer. Moreover, the increased amount of natural sunlight entering the room reduces the use of electricity for lighting up to 25% [1].

Notably, a growing body of literature has demonstrated that exposure to daylight and access to views of nature highly increase the psychophysical well-being of patients and staff [4-7]. Patients treated in rooms with brighter natural lighting experience less pain, take fewer pain medications [8] and have shorter postoperative stays [9]. Moreover, access to daylight can also improve staff alertness and reduce stress levels [10-11].

By increasing the effectiveness of delivering care, reducing the patient Average Length Of Stay (ALOS) and cutting the hospital energy consumption, sunlight amount can dramatically reduce hospital costs [1, 8]. As a consequence, the need of forecasting and assessing this energy and its cost saving potential is a relevant issue.

Nevertheless, the majority of the works available in literature focused on the positive effects of windows on the well-being of building occupants, rarely investigating how these effects change in relation to glazing types, size and room orientation, and especially without simultaneously considering their impact from the energy perspective.

A wide range of research analyzed the positive effects of windows on workers and office environments [12]; some studies examined how office workers perceive different sizes, numbers, positions and degrees of transparency [13-14]. Other studies focused on the beneficial effect of daylight on the well-being and performance of children at schools [15-16]. A limited number of works assessed the role of window proportions in patient satisfaction [17], while only some recent approaches took into consideration window orientation. Among these, Choi et al. demonstrated that in south-east patient rooms the ALOS was 16%–41% shorter than in north-west ones [18]. Other studies analyzed and compared different window glazing types, sizes and orientations from the energy perspective [19-20] in residential buildings [21-22] and in office buildings [23-24]. Besides the studies available in literature, there are several software tools to assess the energy performance of fenestration systems in residential and commercial buildings, like COMFEN (Lawrence Berkeley National Laboratory), EFEN (DesignBuilder) and the MIT Design Advisor (MIT).

However, few studies directly and widely investigated the effects of glazing type, size and window orientation on the energy performance of patient rooms, hindering the construction of a robust and comprehensive reference dataset. Therefore, the purpose of the work was to assess and compare the impact of window size and different kinds of glazing on the heating and cooling energy needs of a patient room in four orientations, to evaluate the energy savings achievable by adopting wider openings and to identify the most effective glazing types.

2. Structure of the method of analysis

To analyse how glazing systems can modify the patient room energy demand as a function of the presence of people, the façade design and orientation, the architectural form, the space layout and distribution, etc. the authors used building energy dynamic simulations. This approach represents a widely and frequently used tool to evaluate the energy saving potential and comfort in large complex buildings under different varying conditions.

The study develops the modelling of the entire building and investigates the energy needs both at single room and at building level, in order to obtain results based on a condition as close as possible to the real situation. The aim is to establish a robust energy data framework and support the designer in selecting the best window glazing when planning a refurbishment of healthcare facilities, or when setting new hospital standards.

The work analyzed only the sensible energy needs since the latent ones are not affected by the glazing type, the window size or the room orientation [25]. The geometric model of the building was generated using Google SketchUp plug-in, while the building and room energy performance have been estimated by means of TRNSYS software, a dynamic building energy simulation program, as opposed to a full-fledged finite element model [26] suffices in this case. Dynamic simulations were conducted with a time step of one hour, using the TRNBuild package and, more in detail, the multi-zone building simulation subroutine called Type 56 [27]. For each selected location, weather data are available from Meteonorm database and weather stations, and they are stored in the weather file that is used by TRNSYS to calculate solar gains [28].

2.1. Description of the case study

The considered hospital is a typical solution of the Italian healthcare building stock, defined on the base of the analysis of six Italian case studies conducted in Ref. [29], and supposed to be located in Bologna (Italy). This city belongs to a humid subtropical climate (Cfa) [30], representative of a wide area of the southeastern United States, the southeastern South America, the Eastern Australia, the Eastern Asia and the most prevalent climate in Italy, together with the hot-summer Mediterranean type (Csa). The building is a L-shaped volume developed on seven stories (Figure 1a), with a quite outdated building envelope and characterized by a covered area of 1,196 m^2, a total conditioned floor area of 6,680 m^2 and a surface to volume ratio (S/V) of 0.41.

A set of simulations has been performed to evaluate the winter and summer energy needs of the whole hospital and of a typical patient room located on the third-floor level of the building. The tested room was assumed to have a volume of 52.50 m^3, with an external wall U-value of 1.43 Wm^{-2}K^{-1} and external area of 7.30 m^2 (Figures 1b and 1c).

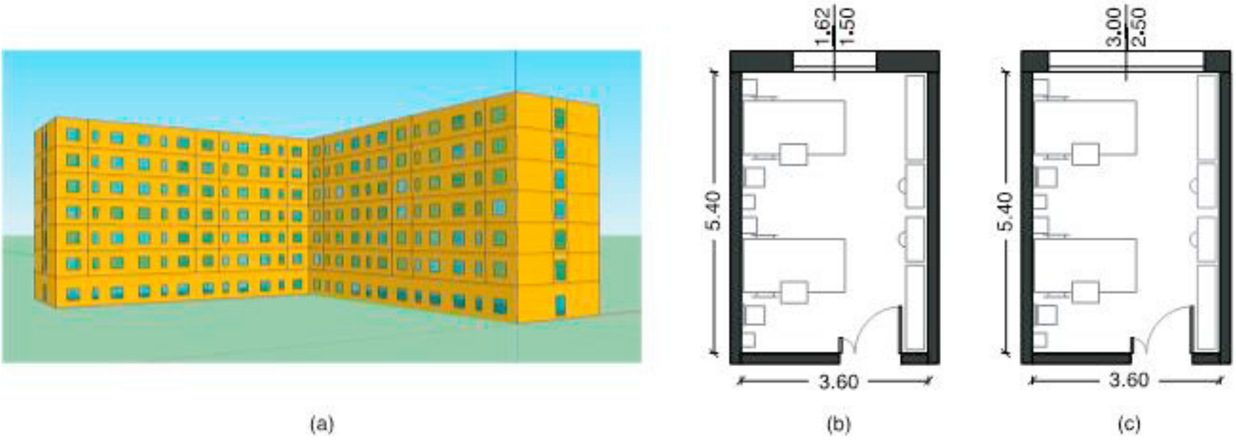


Fig. 1. Perspective view of the reference hospital building (a) and floor plans of the tested patient room with the two different window sizes: 25% WWR window (b) or 77% WWR window (c).

The whole building as well as the patient room analyzed are equipped with an air conditioning system with 24/7 operation schedule [1]. Ventilation load is equal to 1,056 MWh, while heating and cooling set points were fixed at 22°C and 26°C respectively, with 50% relative humidity. Assumed air infiltration rate was of 2.0 volh^{-1} and internal heat gains due to the presence of two patients per room were of 200 W, as defined by ISO 7730 [31]. The longwave emission coefficient of room walls, ceiling and floor were assumed to be 0.9.

Two window sizes, expressed as Window-to-Wall Ratios (WWR), were analyzed for each patient room: a base case window, 1.62 m wide per 1.50 m height, equal to 25% WWR (Figure 1b); a wall-to-ceiling window, 3.00 m wide per 2.50 m height, equal to 77% WWR (Figure 1c).

The second window type, the larger one, was assumed to be protected from sun by a dynamic external shading device. The shading system was designed in order to be activated only in summer and leave exposed to the sun 1.20 m^2 of the window area when solar radiation exceeds about 150 Wm^{-2} (more in detail, 100 Wm^{-2} for a south-orientated façade and 200 Wm^{-2} for a west or east-exposed façade), 0.60 m^2 when solar radiation exceeds 400 Wm^{-2} (for a north-exposed façade) [24], and 0.30 m^2 from 2 to 4 pm, when daytime sleepiness is naturally higher and patients are supposed to take afternoon nap.

Fourteen glazing systems commercially available, with the features indicated in Table 1, were analyzed (generated by means of the software WINDOW 7.5 of the Lawrence Berkeley National Laboratory and then added to the TRNBuild glazing library), for each window size and the four patient room orientations (while frames did not change and had a thermal transmittance of 2.3 Wm^{-2}K^{-1}).

Table 1. Glazing types specifications.

U-value (*Wm^{-2}K^{-1}*)	g-value (*dimensionless*)	composition
2.89	0.789	4/12/4
2.60	0.700	8/20/6
2.10	0.710	4/6/4/6/4
1.20	0.710	4/16/4
2.60	0.650	12/16/4
1.40	0.650	4/6/4/6/4
1.10	0.650	4/16/4
0.70	0.630	4/14/4/14/4
2.10	0.550	6/8/6
1.40	0.550	10/16/6
0.70	0.560	4/16/4/16/4
1.10	0.430	4/16/4
0.70	0.450	4/12/4/12/4
0.50	0.430	4/16/4/16/4

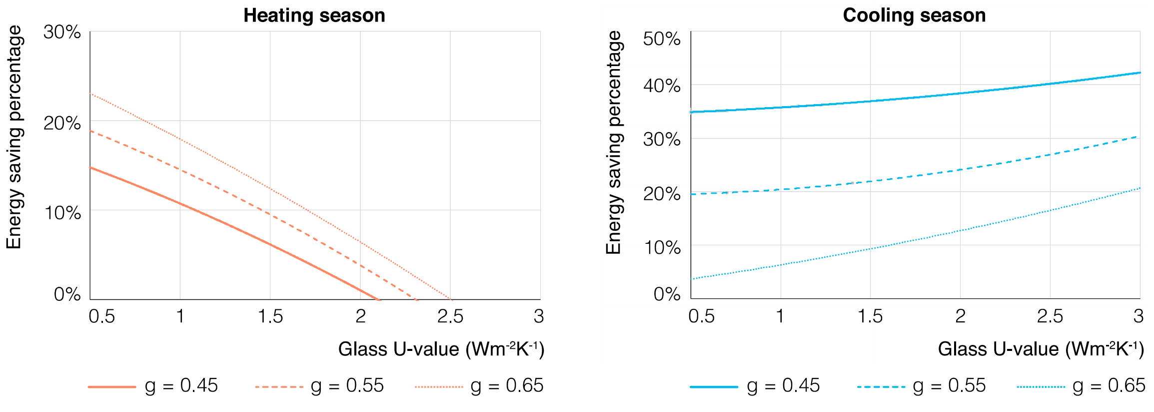
3. Results and Discussion

The results obtained by simulations for a single patient room and the whole building in the city of Bologna are shown in Table 2. Evaluated variables were: the heating and cooling energy needs of the whole building and of the single patient room for each glazing type, WWR, and patient room orientation. Despite the simulations were run for all the fourteen glazing systems, as representative cases, only the results regarding those with a g-value of 0.789, 0.650, 0.630, 0.560, 0.550, 0.450 and 0.430 are reported and discussed below.

Table 2. Heating and cooling energy needs of the whole building and of the single patient room, evaluated for each glazing type, WWR, and orientation.

Glazing properties		WWR (*%*)	orientation	Single patient room		Whole building	
U-value (Wm^{-2}K^{-1})	g-value (*dimensionless*)			Q_{H_r} (*kWh*)	Q_{C_r} (*kWh*)	Q_{H_b} (*kWh*)	Q_{C_b} (*kWh*)
2.89	0.789	25	W – E	3,244 – 3,253	394 – 377	1,606	70
			S – N	2,989 – 3,412	337 – 217		
		77	W – E	3,331 – 3,347	394 – 404	1,616	72
			S – N	2,739 – 3,706	380 – 376		

2.60	0.650	25	W – E	3,257 – 3,264	326 – 312	1,617	59
			S – N	3,043 – 3,397	280 – 187		
		77	W – E	3,342 – 3,355	325 – 330	1,627	60
			S – N	2,847 – 3,652	308 – 307		
1.40	0.650	25	W – E	3,071 – 3,079	336 – 322	1,560	60
			S – N	2,858 – 3,210	285 – 192		
		77	W – E	2,795 – 2,808	357 – 363	1,494	64
			S – N	2,309 – 3,095	337 – 334		
1.10	0.650	25	W – E	3,045 – 3,053	338 – 325	1,553	61
			S – N	2,834 – 3,184	292 – 195		
		77	W – E	2,718 – 2,733	366 – 374	1,477	66
			S – N	2,242 – 3,020	351 – 346		
0.70	0.630	25	W – E	3,004 – 3,012	330 – 317	1,542	59
			S – N	2,798 – 3,138	281 – 190		
		77	W – E	2,591 – 2,605	361 – 367	1,449	64
			S – N	2,128 – 2,880	314 – 307		
2.10	0.550	25	W – E	3,196 – 3,204	296 – 284	1,602	54
			S – N	3,004 – 3,323	255 – 174		
		77	W – E	3,153 – 3,165	300 – 304	1,587	55
			S – N	2,711 – 3,428	284 – 282		
1.40	0.550	25	W – E	3,099 – 3,106	299 – 287	1,573	54
			S – N	2,909 – 3,224	260 – 177		
		77	W – E	2,864 – 2,876	315 – 321	1,517	58
			S – N	2,433 – 3,134	301 – 297		
0.70	0.560	25	W – E	3,032 – 3,040	297 – 285	1,553	54
			S – N	2,849 – 3,153	257 – 176		
		77	W – E	2,663 – 2,676	322 – 327	1,470	58
			S – N	2,251 – 2,920	306 – 302		
1.10	0.430	25	W – E	3,133 – 3,139	233 – 225	1,591	44
			S – N	2,984 – 3,231	206 – 147		
		77	W – E	2,943 – 2,952	241 – 244	1,547	45
			S – N	2,615 – 3,148	229 – 227		
0.70	0.450	25	W – E	3,084 – 3,090	244 – 234	1,575	45
			S – N	2,929 – 3,185	214 – 151		
		77	W – E	2,797 – 2,807	256 – 259	1,510	48
			S – N	2,456 – 3,009	243 – 240		
0.50	0.430	25	W – E	3,081 – 3,088	234 – 225	1,576	43
			S – N	2,933 – 3,178	204 – 147		
		77	W – E	2,787 – 2,796	245 – 247	1,510	46
			S – N	2,462 – 2,988	231 – 229		



(a) (b)

Fig. 2. Achievable saving on (a) heating and (b) cooling energy needs of the west-facing "base case" adopting the 77% WWR window in relation to its U-value and g-value.

Since the trends of heating and cooling needs observed with different orientations of the glazing types were similar, the following analysis only focused on the data concerning the window with 77% WWR facing west.

Furthermore, taking into account the technical obsolescence of the healthcare building stock, the scenario of 25%WWR window with U-value of 2.89 $Wm^{-2}K^{-1}$ and g-value of 0.789 was considered representative of the state of the existing hospital. Therefore, this condition was assumed as the reference condition of potential energy savings, and it was called the "base case". In Figures 2 and 3 the achievable savings on the heating and cooling energy needs vs the "base case" are shown, supposing to adopt a 77% WWR window while varying the glazing specifications.

A first analysis of the data reported in Table 2 highlight that, in absolute terms, the heating energy needs impact the total energy requirements of the patient room more than the cooling ones. However, the comparison of the percentage achievable savings shows that potential savings on cooling energy are more relevant, reaching a value of about 40% compared to the maximum savings on heating energy, equal to 25% (Figures 2b and 3).

The values of the "base case" energy needs and of the potential savings by using a 77% WWR window and varying the U-value and g-value are outlined in Figure 3. The data show that for the city under investigation it is more important to choose the most effective glazing for the heating period. Indeed, appropriate values of glazing specifications to reduce heating energy demand are opposite to those necessary to reduce the cooling one (Figure 2).

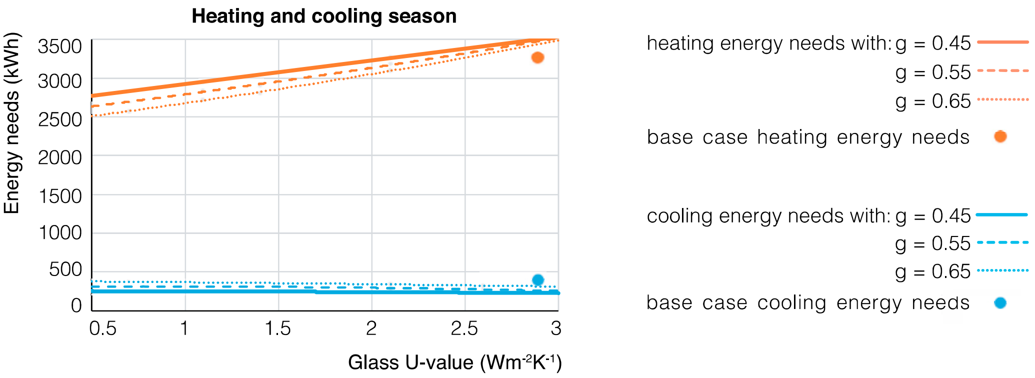


Fig. 3. Heating and cooling room energy needs for the west-facing window with 77% WWR in relation to its U-value and g-value compared to the energy needs of the "base case".

Taking into account both the heating and the cooling period, the research results show that it is not energy-efficient to adopt glazing with either high or low U-value and g-value.

4. Conclusions and future developments

We found a significant discrepancy between the values of the heating energy and the cooling needs, a difference between the achievable percentage savings, as well as an opposite trend between the glazing specifications allowing to reach the maximum heating energy savings and those appropriate for the cooling ones. These observations highlight the need to consider the two types of energy demand separately. More into detail, for each geographic location it is necessary to examine the weather data in order to figure out which energy needs are more relevant. In the case of the city of Bologna, we focused on the heating energy requirements since they are more relevant than the cooling ones. Besides to the climatic condition, this is due to the high heating set point, fixed at 22°C, and the use of external shading systems, which further reduced the cooling energy needs.

With appropriate glazing specifications, the adoption of wider windows enables to reduce the patient room heating energy requirements by increasing the amount of solar heat gains and minimizing the thermal transmission losses. However, windows with higher WWR increase the cooling energy needs, which can be significantly reduced using appropriate glazing types and shading systems.

To optimize winter and summer energy needs, our results indicate that in the case of a city with climatic data similar to Bologna, it is necessary to adopt glazing types in a range of 1 to 2 $Wm^{-2}K^{-1}$ U-value and g-value around 0.55.

For a comprehensive interpretation of the results regarding the achievable energy savings and future developments it is necessary to highlight underline that additional savings on heating requirements could be obtained by activating the shading systems during the night in the heating period, to further minimize the thermal losses.

One of the future developments of the study will be to conduct a cost-optimal analysis of the investigated solutions to develop a robust decision-making tool. Moreover, to build a more comprehensive energy dataset, other cities with climatic conditions similar to Bologna could be included in the model. Finally, extending the analysis to cities with higher winter solar gains and smaller cooling requirements, will allow to study whether the adoption of wider windows could reduce the patient room energy needs.

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