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High-Performance Glazing for Enhancing Sustainable Environment in Arid Region's Healthcare Projects

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Abstract: The integration of sustainability rating systems in healthcare projects and healthcare building envelope specifications is a growing concern in the construction industry, especially in the arid region. The external facade of healthcare buildings is one of the most significant contributors to the energy cost and comfort level of healthcare buildings in such a region. This study undertook a comprehensive comparison analysis of an adaptive model of high-performance glazing (HPG) specifications for patient rooms in a case study inside Saudi Arabia based on multi-criteria, including the LEED Healthcare rating system. The study used a technical comparative analysis for three onsite glazing models with HAB software v6.0 based on specifications of specialist manufacturer organizations for glazing window performance, climatic conditions, and the region's culture. Significant results in the case study project were achieved in energy saving and sustainability ranking in the healthcare rating system, providing new specification guidelines for HPG applications in healthcare buildings located in an arid region, and cultural environment considerations.

Keywords: healthcare rating system; high-performance glazing (HPG); green hospitals; sustainable environment; arid region

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Citation: Ismaeil, E.M.H.; Sobaih, A.E.E. High-Performance Glazing for Enhancing Sustainable Environment in Arid Region's Healthcare Projects. *Buildings* **2023**, *13*, 1243. https://doi.org/10.3390/buildings13051243

Academic Editors: Yingdong He and Nianping Li

Received: 19 April 2023
Revised: 30 April 2023
Accepted: 5 May 2023
Published: 9 May 2023

1. Introduction

A green hospital recognizes the connection between physical and mental human health and the environment to demonstrate its governance, strategy, and operations [1–3]. A green hospital building enhances patient well-being, promotes public health, reduces environmental impact, contributes to the elimination of disease burden, and aids the curative process, while utilizing natural resources in an efficient, environment-friendly matter [4,5]. Green hospital rating systems are considered in both construction and operation and provide a therapeutic environment in which the overall design of the building contributes to the healing process and reduces the risk of healthcare-associated infections rather than simply being a place where treatment takes place [5,6]. The healthcare planning and design process needs to be correspondingly broad enough to include not only the issues surrounding the treatment of disease but also the promotion of health and prevention of disease—essentially the creation of a safe and therapeutic care environment [7–9]. Therefore, the design of a green hospital considers lighting, indoor air quality, passive and active measures, clean and green interior building materials, and the landscape. Table 1 illustrates sustainability rating tools and organization for healthcare buildings [9,10].

Identifying precisely the external glazing elements specifications in healthcare building facades supports architects and contributes to achieving a green hospital. They also help in achieving sustainability conditions and elements, which include indoor air quality and using natural materials and resources without any harmful content to reduce CO_2 monitoring. They also help in providing desirable and better daylight transmission; contributing with new energy-saving technology; reducing solar heat gain in hot climates and preventing heat loss in cold climates; supporting safety benefits needs; enhancing occupant comfort, improving the productivity of occupants; and supporting patient recovery, healing, and connectivity to the external environment view. Figure 1 illustrates the benefits of using glazing elements in hospitals facades [8,9]. The processes and practices of sustainability focus on the green healthcare structures' design, justify architectural approaches to interior design in a healthcare setting, and improve the quality of services to the hospital occupants [10,11].

Table 1. Sustainability rating tools and organization for healthcare buildings.

Issues and Elements for Rating		**International Organization Rating Green Healthcare Building**
Construction	Operation	BREEAM
Integrated Design	Integrated Operation	LEED
Sustainable Sites	Sustainable Education	GREEN STAR
Water Efficiency	Sites Management	DGNB
Energy + Atmosphere	Transportation	FGI
Materials + Resources	Facilities Management	WHO "The World Health Organization"
Environmental Quality	Chemical Management	
	Waste Management	LEED
	Environmental Services	WELL
Innovation + Design Process	Food Service	WELL
	Environmentally Preferable Purchasing	EPA
	Innovation in Operation	ISO

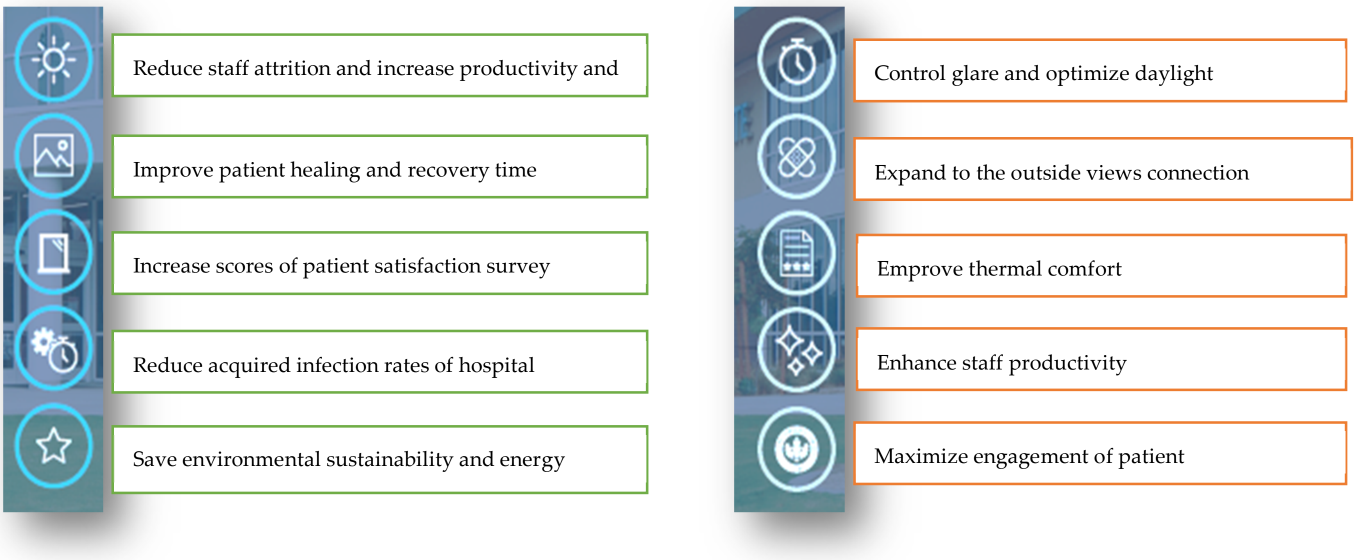


Figure 1. Benefits of using glazing elements in hospitals facades.

Designing green and healthy environments for patients, staff, and visitors' physical and mental well-being in hospital buildings is a significant concern for all international and local organizations [12,13]. Enhancing the formulation of the requirements for healthcare architectural design elements and the building system positively affects the relationship between the indoor environmental quality (IEQ) performance and the overall inpatient satisfaction [14,15]. Green building rating systems (GBRSs) are adopted worldwide to investigate the most effective glazing types in hospital patient room buildings, which affect the performance of IEQ, occupants' satisfaction in a hospital ward, heating, and cooling energy needs [6,16–18]. The healthcare façades, which include HPG elements with special specifications, can achieve a better balance between occupants' satisfaction and the building energy demand, well-being, privacy in clinic diagnosing, daylight transmission, occupant comfort inside the hospital spaces, energy saving, and a reduction in CO_2 [19–24].

1.1. High-Performance Glazing (HPG) Elements Specifications and Sustainability

The term 'high-performance building' is commonly applied to both buildings and their facades, and often to the materials that they comprise, such as high-performance glass [25,26]. The exterior enclosures of high-performance sustainable facades use the minimum possible amount of energy to maintain a comfortable interior environment and to create a healthy and productive environment [27,28]. A high-performance building optimizes the integration of all high-performance attributes through a life cycle basis, including energy conservation, durability, safety, accessibility, and the operation processes' cost [29,30]. Therefore, the attributes for determining the performance of the building facades include: first, environmental impacts of the building facade, including energy consumption and resulting emissions over the operations phase of the building lifecycle, as well as lasting impacts; second, the building occupant security and safety using the façade's system; third, durability, which is the fundamental aspect of performance and sustainability for all building systems; fourth, the economic or cost benefit, and the efficiency of all facade systems and materials; fifth, human comfort, which affects the productivity, e.g., thermal, acoustic, daylight, visuality, and connection to the natural environment. The benefits of high-performance skins provide the occupants with fresh-air exchanges, collecting solar energy through various technologies, harvesting rainwater for cistern storage and water heating, and providing daylight and views to occupants while minimizing glare [31–33].

The technical description of high-performance glass provides energy efficient, resistant glass, safety, and glass with electrically charged interlayers [34]. The innovations in glass and glass coating technology provide control over solar radiation, maintain the virtually neutral appearance, and provide a high light transmission [35]. The benefits of using HPG include an energy saving of 35–40% more than conventional glass, a payback period from 3 to 4 years, and enhancing the occupant comfort and productivity by accessing daylight [36]. The common parameters and values to measure the internal comfort status for the whole glass in HPG include [13,16]: first, visible light transmittance, which varies between 0 and 1; second, the solar radiation admitted through a window, which is addressed with the solar heat gain coefficient (SHGC), expressed between 0 and 1; and third, the U-factor, which measures the resistance heat flow from the building to outside, where its ratings are between 0.15 and 1.20 [17,18].

1.2. Types of High-Performance Glass

The different types of high-performance glass include: first, insulated double and triple-glazed glass, which consist of two or more glass panes with an air space filled with inert gas, e.g., argon and krypton, which resists the heat flow and can reduce the U-value by 0.2–0.3 W/m^2K [21]; second, tinted glass, which reduces the solar heat gain coefficient and visible light transmittance using common colors, e.g., blue, green, gray, and bronze [21,22]; third, reflective glass coatings, which usually consist of thin metallic layers with a variety of colors, e.g., silver, gold, and bronze, applied on the outer surface of the glazing, where the reflective coatings enhance the transmittance of clear glass from 89% to more than 96% and the reflectivity from 8% to less than 2% [22]; fourth, triple-silver-glass coatings, where a third silver layer is added to enable a high light transmission and low solar factor [21,23]; fifth, low-iron glass or ultra-clear glass, which reduces the iron content to produce beautifully transparent results, with a high safety, transmittance, aesthetics, and environmental friendliness [22–24]; sixth, vacuum-insulated glazing, which is used to minimize conduction and convection heat losses [25]; seventh, solar control low-E glass, which is a special oxide-coated glass that transfers a lower amount of heat in the building, reducing the glare of light entering and the cost of artificial lights, with excellent thermal insulation properties and an emissivity of 0.84, which means that it absorbs 84% of long-wave radiation and reflects 16% [26,27]; eighth, smart glass and laminated glass or switchable transparent glass (STG), which are used as smart PDLC film to change between clear and opaque using voltage control [27,28].

1.3. Compatibility Factors of Glazing Elements with Sustainability Rating System

There are many advantages in the composition of glazing elements in all types of healthcare building facades because of their aesthetic specifications and positive technical environmental effects commensurate with the modern standard in healthcare construction projects, which aims toward being green healthcare projects with a high ranking in achieving sustainability requirements and patient-healing needs [30,31]. The attainment of these requirements and needs can be illustrated and classified in a compatibility matrix by reviewing the most important standards required by the USGBC (LEED Healthcare Guideline 2009), Guideline for Design and Construction of Health Care Facilities FGI "Facility Guidelines Institute", and the use of technical specifications of glazing elements from specialized manufacturer companies, e.g., Saint-Gobain, Guardian, and Pilkington, and aluminum companies such as Choco and Technal [32]. The domains of the environmental performance of sustainable healthcare construction include: site selection, alternative transportation, water conservation, energy efficiency, recycled materials, renewable systems, low-emitting materials, natural daylight, waste generation reduction, and local organic food [33,34].

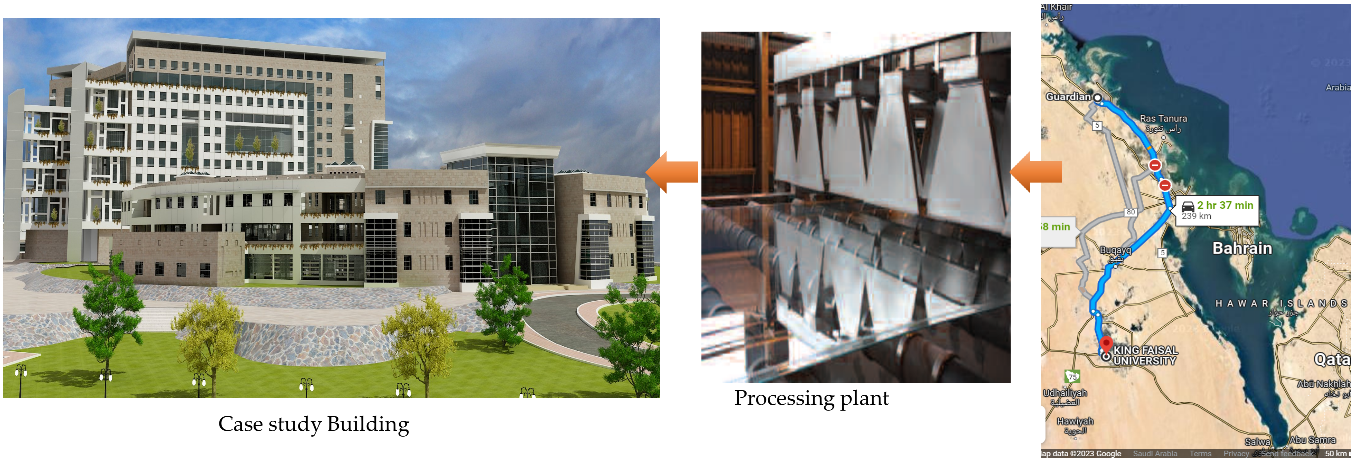
The Leadership in Energy and Environmental Design (LEED) system is widely recognized as a green building standard in the construction industry, and provides a framework for healthy-environment, high-efficiency, low-carbon, and cost-saving green buildings. The LEED rating system is an evaluation system used for the building's environmental performance and sustainability measurements, which are based on an points-earning system for meeting certain criteria in categories such as the buildings' indoor environmental quality, water conservation, and energy efficiency [32]. The LEED rating system has an emphasis on energy efficiency and renewable energy, using energy-efficient equipment and systems such as high-efficiency HVAC systems, LED lighting, solar panels, and analytics data platforms, and using renewable energy sources such as geothermal, wind, or hydroelectric power. The LEED certification has four levels: Certified (40–49 points), Silver (50–59 points), Gold (60–79 points), and Platinum (80+ points), through a continuous review process that includes a pre-certification review, a construction review, and a post-construction review [33].

The LEED for Healthcare rating system is provided for inpatient and outpatient healthcare facilities and its content is specific to designing strategies relevant to healthcare environments. LEED-certified sustainable hospitals contain specific criteria values as optimal green healthcare environments that influence the patients' health, well-being, and recovery periods. The base of the standards is classified into categories of location and transportation, sustainable site, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation and design process, and regional priority [33,34]. Improving the high-performance glazing (HPG) specifications in healthcare projects can achieve more points in the LEED rating system and improve sustainability in the three main sustainable categories of the whole project.

First: in the energy and atmosphere (EA) category, HPG can help to achieve more points in EA Credit 1 (1–24 points) and optimize the energy performance to achieve increasing levels by demonstrating a percentage improvement in the proposed building performance [37,38]. Moreover, regarding EA Credit 2 (1–8 points), which concerns onsite renewable energy, the intent for this category is to encourage increasing on-site renewable energy self-supply levels by using on-site renewable energy systems to offset building energy costs. Figure A1 (Appendix A) shows a technical performance comparison between clear and tinted glass [38]. The HPG can contribute to these two credits by obtaining the best energy-efficient glazing, which combines thermal insulation and solar with increasing the SHGC value from 0.20 to 0.25 as required in EN 410, NFRC 200, and NFRC 300 (American Standard) [35]. Moreover, it helps in achieving a combination of solar control and low emissivity by installing, as an example, high-tech HPG such as transparent conductive oxide (TCO) as cover plates, electricity generation, and hot water, including certain types of solar materials, e.g., crystalline silicon photovoltaics, thin-film photovoltaics, concentrated solar power applications, and solar thermal collectors. Figure A2 (Appendix A) shows crystalline, amorphous, and coating type used to generate power to reduce air conditioning (AC) loads and CO_2 emissions [36].

Second: in the indoor environmental quality (IEQ) category, HPG can help to achieve more points in IEQ Credit 2 (1–2 points), which concerns the acoustic environment, in order to provide building occupants with an indoor healing environment free of intrusive or disruptive levels of sound to meet the 2010 FGI Guidelines on control site exterior noise [37,38]. HPG can contribute to noise reduction according to noise reduction coefficients (NRCs), traffic loads, and the thickness of glass layers as follows: traffic, 30–50 db reduction; non-traffic, 35–40 db reduction [36,39]. HPG also helps to achieve more points in IEQ Credit 4 (1–4 points), which concerns low-emitting materials, by reducing the quantity of indoor air contaminants that are odorous, irritating, and harmful to the well-being and comfort of patients. Therefore, HPG can protect a healthy indoor environment from pollution, characterized by a level of formaldehyde and volatile organic compound (VOC) emissions close to 0 in materials and systems, e.g., coated glass, tempered glass, the sealant, and the PVB layer in laminated glass [40]. HPG also contributes to IEQ Credit 5 (1 point)—the control of potentially hazardous indoor chemical and pollutant sources to minimize their exposure to building occupants—by using silver ions in the upper layers of the glass, which destroy bacteria and germs by disabling their metabolism and disrupting their division mechanism, particularly in warm and moist conditions, where the glass coating supports the antibacterial process as shown in Figure A3 (Appendix A) [24,41,42]. Furthermore, HPG helps to achieve points in IEQ Credit 6.2 (1 point), which indicates the controllability of systems' thermal comfort, by providing a high-level-of-thermal-comfort system and individual thermal comfort controls for the patient room [37–39]. HPG can achieve a high level of insulation by using double or triple-insulating glazing and coated glass in the range of approximately 8″ c to 15″ c (IRUV coating as an example) [25,43,44], resulting in a reduction in the solar factor, increase in the thermal insulation value, a 25% energy-saving value, 70%:80% visible transmittance, a U-value as low as 0.9, and a 2:5 year payback [23,37]. Figure A4 (Appendix A) illustrates one of the job references used: transparent coating tested in a lab with a 15% reduction in insulation [42,45]. HPG contributes to both IEQ Credit 8.1 (1 point)—daylight—and IEQ Credit 8.2 (1 point)—daylight and views—by providing building occupants with a connection between the outdoor environment and indoor spaces through daylight and views that reach regularly occupied areas of the building [46,47], achieved by calculating the window-to-floor area ratio (WFR), window-to-wall area ratio (WWR), and window head height. HPG can achieve a wide variety of visible light transmittance, ranging from 10% to 83% [48]. Therefore, the glass connects building occupants with the outdoor views and reduces the use of electrical lighting [45]. The design of the window glazing could serve to be compatible with dim electrical light systems as well as allow for the achievement of a suitable angle and WFR ratio. On average, hospitals require an ambient light of 500 to 1000 Lux for visual comfort. Figure A5 illustrates the different types of integrated window and curtain wall structures with thin and photovoltaic film in visible light transmittance (LT). Figure A5 (Appendix A) shows different types of integrated window-and-curtain-wall structures with thin and photovoltaic film in visible light transmittance [46].

Third: in the materials and resources (MRs) category, HPG can help to achieve more points in MR credit 3 (1–4 points), which concerns sustainably sourced materials and products, by using the recycled content value and the cost of the assembly, as well as materials and products whose source/manufacture must not exceed 500 miles (800 km) from the project location [46,49]. The manufacturing measurements and local raw materials of HPG in Saudi Arabia comply with the current edition of the ASTM E966 Standard [50,51]. All glass factories are within 800 km from inside SA, and they have a minimum of 30% recycled glass [49,52]. Figure 2 shows the locations of the glass manufacturer for the case study far 239 km from the case study location.



Case study Building

Processing plant

The location of glass

Figure 2. Locations of manufacturing processes that produce glass for the case study.

The study presents an evaluation process for HPG specifications guidelines that could be applied in public and private healthcare projects in arid regions to have a positive impact regarding the external environment, meet the patients' healing needs, indoor patient comfort, caregiver performance, and patient and staff satisfaction, and provide excellent solutions for growing convergence that fosters public health and environmental sustainability.

This study undertook a full analysis of compatibility factors of HPG elements with sustainable rating system credits and international standards in order to update tender specifications and achieve distinguished results in energy saving, indoor air quality, and other sustainability goals, using King Faisal University (KFU) teaching hospital as a case study. This study examined energy conservation and the sustainable rating level in a public healthcare project in a desert campus area based on numerical analysis with HAP software v6.0, considering LEED for Healthcare as parameters for a sustainable rating system, in order to evaluate three HPG alternatives in the case study hospital in terms of their effectiveness in improving the hospital efficiency. The study adapted new specifications for HPG, energy saving, and more than 13 points in LEED for Healthcare that could be earned in the case study hospital. These significant results were accomplished according to partnerships between several agencies (e.g., the campus technical team, the national energy service, private glass manufacturers, and municipal governments). The study presents new applicable HPG specification guidelines to be addressed in the HPG local construction regulations and codes for public and private healthcare projects in arid regions. This will support gaining sustainability points in the rating system and linking positive external environment impacts with patients' healing needs, indoor patient comfort, caregiver performance, and satisfaction, which are excellent solutions for growing convergence that foster public health and environmental sustainability.

2. Methodology

The technical analysis and numerical evaluation of the external glass composite, e.g., curtain walls, windows, and doors in healthcare construction projects, are considered as essential processes for improving energy performance and adapting the external and internal environment toward supporting sustainability, comfortability, and well-being of all patients, staff, and visitors. This study addressed the benefits of improving energy performance, sustainability value, and culture needs in the inpatient ward in a healthcare case study construction project according to the technologies used to improve the performance of the facades and international sustainability rating system.

The study performed technical analysis, with HAP software [53] for energy simulation, LEED Healthcare rating system, and physical monitoring with technical team of experts and decision makers for three actual high-performance external window alternative samples in ongoing teaching hospital facades as a case study in Saudi Arabia between 2020 and 2021 before installing the facade windows in the actual site. The authors of the study, with an expert team that included a project manager, an aluminum manufacturer specialist in specifications, and a mechanical engineer specialist with HAP software, as well as interviews with specialist medical staff, established, as an expert judgment of the analysis processes within, the following stages:

1. Gathering all available data and explaining the compatibility matrix between external glazing elements and LEED Healthcare sustainability credits as a sustainability international rating system related to healthcare projects. These include (A) energy and atmosphere regarding optimizing energy performance and onsite renewable energy; (B) indoor environmental quality (IEQ) in the acoustic environment, indoor chemical and pollutant source control, low-emitting materials, daylight and views, and thermal comfort system controllability; and (C) materials and resources (MRs) regarding sustainability sourced materials and products.
2. Interviews with experienced medical staff in analyzing the impact of the connection between indoors and outdoors through the external building envelope on patient healing and well-being in public hospitals.
3. The project aluminum manufacturer installing three actual samples of glazed windows as per bidding dimensions: one as per tender specification, and the other two samples each having different glass specifications, including transmittance (LT), reflectance (in), shading coefficient SC, U value, reflectance (out), privacy, and color, in order to make a physical evaluation by expert judgment committee.
4. Conducting technical and numerical comparisons using HAP software for the three samples to identify the compatible sample with sustainability standards, the required privacy degree in the patient room according to environment culture, and natural light for improving the well-being of the patient.

The study adopted technical analysis for the energy performance and sustainability rating in the window glazing case study for improving the tender specifications. The study undertook numerical and technical comparison for the three actual alternative samples installed by the aluminum supplier before installation in the site as a procedure in order to achieve sustainability in one of the important external façade elements, which have a direct effect on inpatient healing, privacy, comfortability, and satisfaction. The study submitted a pioneer example of updating HPG window specifications for healthcare construction projects in arid areas to be addressed in regulations and codes of desert healthcare construction projects. Figure 3 shows the study method flowchart.

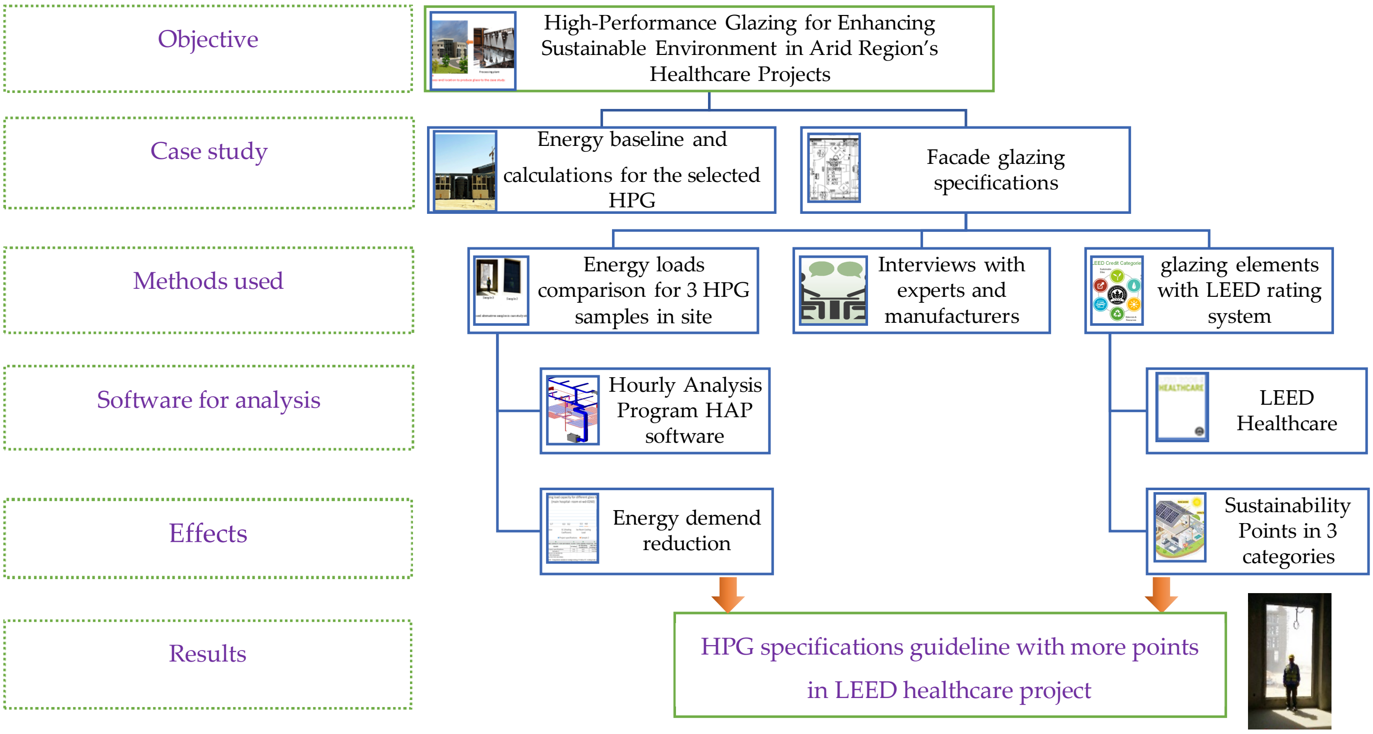


Figure 3. The study method flowchart.

Applying High-Performance Glazing HPG in King Faisal Teaching Hospital Facades

The public teaching Hospital located at King Faisal University (KFU), Saudi Arabia, consists of five buildings (main building, outpatient, physiotherapy, oncology, and multi-story parking). Building 02, which is the outpatient hospital, was particularly designed for complete examination in clinics and laboratories to test and determine exact illness results for diagnosis. The built area of outpatient building B02 is 45,000 m^2, and its skeleton structure is composed of four levels with 29 clinics on three floors and staff parking on the basement floor. Building B02 contains 448 m^2 of structural glazing elements for the whole building, and the total load for cooling reaches approximately 2841 kw, where the tender specifications of glazing elements include non-intensive clinic dimension of 1.8 m $\times$ 3.0 m (5.40 m^2), intensive clinic dimension of 1.8 m $\times$ 2.4 m (4.32 m^2), 2 units of sensitive medical clinics with dimension of 0.6 m $\times$ 2.4 m (2.88 m^2), with insulating clear double-glazed bronze color, tempered, 24 mm thick 6 mm external pane, 6 mm internal pane, and 12 mm sealed air space in between panes, and cooling load for each window of 5.5 kw. Figure 4 illustrates the outpatient ward façade and Figure 5 illustrates the outpatient building B02 inpatient ward plan [54].

Project tender specifications of glass and glazing structure were designed to have its final composition be 24 mm thick insulating double-glazed, 6 mm thick bronze color float and tempered glass for the external pane, and 6 mm thick clear float and tempered glass for the internal pane, with 12 mm distance of sealed air space in between panes. In addition, the shading coefficient was designed to be SHGC 0.3%, with protective UV value of 2.5 W/m^{2}K, without mentioning any other conditions for maximum relative heat gain (RHG) or daylight visibility transmittance (LT). These specifications was limited regarding the achievement of sustainability requirements for the patient healing, staff, employees, and visitors. Therefore, the authors and KFU experts committee built the methodology based on choosing the suitable specifications from a comparison of alternatives for three real samples manufactured by the approved aluminum supplier according to different specific specifications, e.g., daylight transmittance (LT), glare reflectance (in), shading coefficient (SHGC), protective U-value, glare reflectance (out), privacy, and color.

Figure 4. Outpatient ward façade.

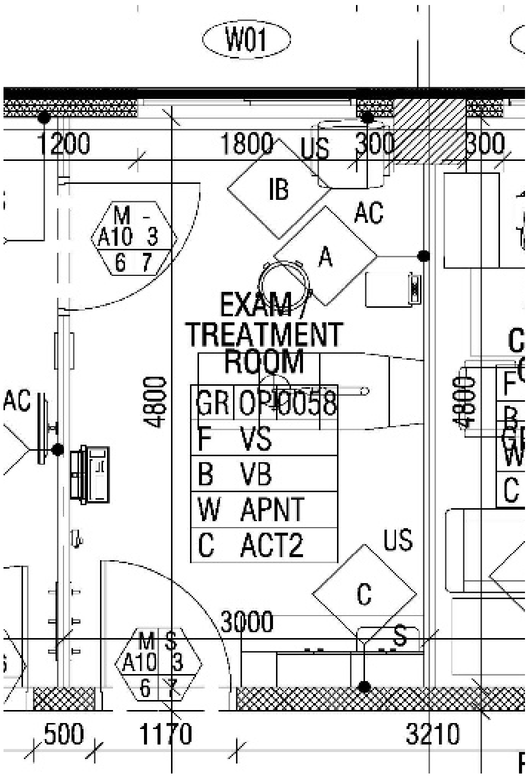


Figure 5. Outpatient ward plan.

Table 2 illustrates the specification comparison sheet for the following: Sample one: daylight visibility transmittance 18%, glare reflectance agreed (in) 13%, shading coefficient 0.2, U-value 1.74, glare reflectance agreed (out) 13%; Sample two: daylight visibility transmittance 27%, reflectance (in) 11%, shading coefficient 0.3, U-value 1.8, reflectance (out) 8%; Sample three: daylight visibility transmittance 4%, glare reflectance (in) 49%, shading coefficient 0.18, U-value 2.4 W/m^{2}K; glare reflectance (out) 15%. The committee made a practical comparison on site in order to select the suitable alternative based on achieving the degree of sustainability requirements within compatibility matrix between glazing elements and LEED sustainability credits.

Table 2. Specifications comparison sheet for the three real samples.

Specification	Tender Project Specification	Sample 1	Sample 2	Sample 3
Transmittance (LT)	-	27%	18%	4%
Reflectance (in)	-	11%	13%	49%
Shading Coefficient (SC)	0.3	0.3	0.2	0.18
U-value	2.5	1.8	1.7	2.4
Reflectance (out)	-	8%	13%	15%
Privacy	-	Less privacy	Medium	More privacy
Color	-	Grey	Between grey and brown	Brown

Figure 6 illustrates real alternative samples erected on site in the outpatient building façade to facilitate physical and realistic comparison with the international standard recommended by the international manufacturer, such as Guardian, Obeikan, and Pilkington, to support the authors and KFU-authorized committee in choosing applicable high-ranking sample and achieve the following advantages: compatibility between capabilities of glazing elements with new technology manufactured from internationally experienced glass manufacturers such as Onyx, AGC Obeikan, and Guardian, and LEED for Healthcare 2009 guide as sustainability requirements standard mentioned in Table 2, which focuses on: (A) energy and atmosphere (EA) regarding optimizing performance of energy and renewable energy onsite; (B) indoor environmental quality (IEQ) in the acoustic environment, concerning indoor chemical and pollutant source control, low-emitting materials, daylight and views, and thermal comfort systems; (C) materials and resources (MRs) regarding sustainably sourced materials and products, all considering the international standard, codes, and requirements in glazing elements and green hospitals such as European Norm EN 410 and EN 673, as well as American standards such as NFRC 100/200/300 [55–57]. The results from using HAB software program to calculate energy saving in cooling load provide decision maker with quantitative applicable alternatives approach to enhance the glazing windows' tender specifications and save energy for cooling system in outpatient building regarding the project life cycle.

Sample 1 Sample 2 Sample 3 Sample 2 Sample 1 Sample 3

Pictures from inside Pictures from outsid

Figure 6. Proposed alternative samples in case study site for outpatient ward.

3. Results and Discussions

After using HAP software to perform the analysis for the alternative specification and comparing the alternative specification with both sustainability requirements in LEED for Healthcare 2009 and requirements in glazing elements and green hospitals, in the study, the KFU-authorized committee and author chose sample two as HPG with a shading coefficient of SHGC 0.21%; a protective UV-45 value of a maximum of 1.74 W/m^{2}K, considering the season of summer and expecting to control the relative heat gain with a maximum RHG of 149 W/m^2; and a transmittance (LT) of 18% with a glare reflectance agreed to be 13% on both the inside and outside. These choices were made according to the following results.

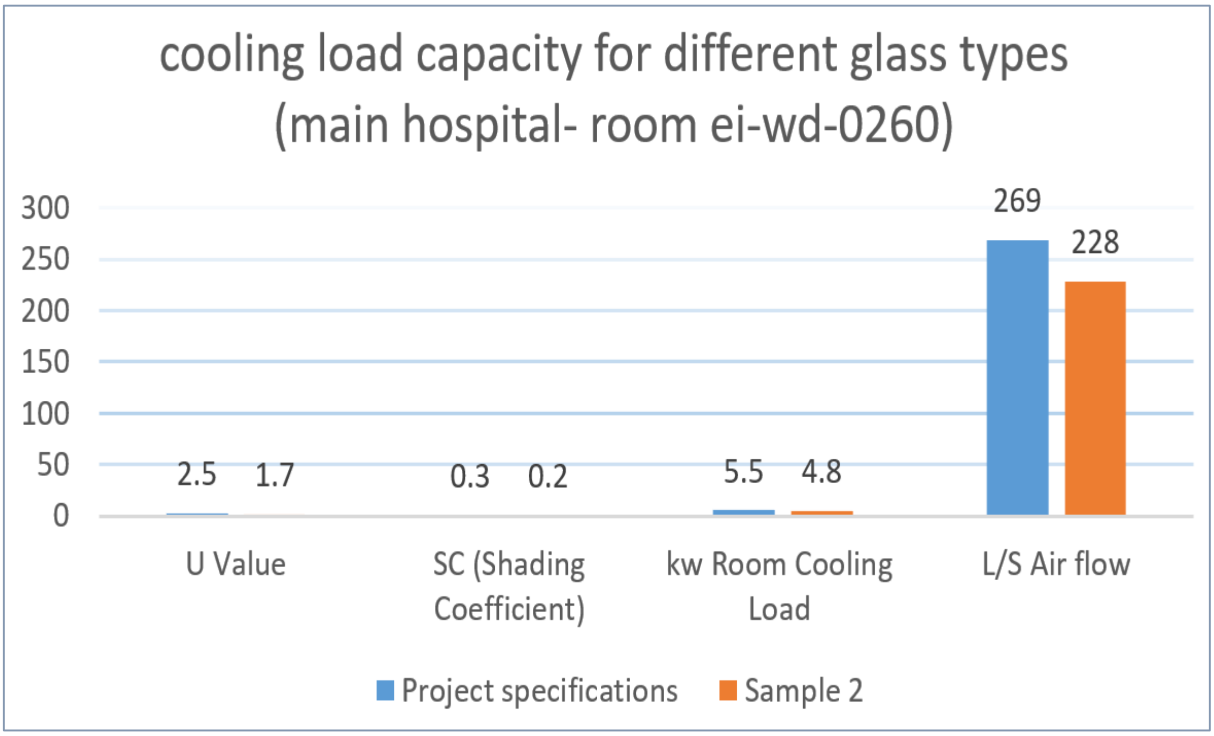
Sample two follows international organizations that focus on sustainability and green healthcare construction and have codes and credits, e.g., European Norm (EN), The National Fenestration Rating Council (NFRC), the glass manufacturer ONYX, and the glass manufacturer AGC Obeikan. The technology used for the installation of glass coating involved a transparent microscopically thin coating on the glass to reduce the heat gain into the building [57–59]. Table 3 illustrates a comparison between tender specifications and sample two specifications, which assure that sample two specifications are compatible with the glass international standard requirements and achieve significant results.

Table 3. Technical comparison factors for choosing alternative sample with tender specifications.

Glass Thickness 6t + 12air + 6t	U-Value	Shading Coefficient SC	Transparency Lt	Reflectance (in) %	Reflectance (out) %	Room Cooling Load KW	Energy Saving (1–10)
Tender	2.5	0.3	N/A	N/A	N/A	3.4	5
Sample two	1.74	0.21	18	13	13	3.1	7

The HPG specifications of sample two support the needed cooling load reduction, enhance the air flow inside the inpatient room, and compensate for the tender specification shortage. Fully detailed descriptions for zone sizing and energy modeling are illustrated in Figures A6 and A7 (in Appendix B). Figure A6 shows a zone sizing results summary for the fan coil of maximum tender specifications, and Figure A7 shows a zone sizing results summary for HAP software of the fan coil of sample two. The result of the comparison between the two instances of zone sizing indicates a 13% reduction in the cooling load and 15% reduction in the air flow needed for cooling energy after applying sample two. The other advantages are illustrated in Figure 7, which shows significant results of a comparison of elements, e.g., U-value, shading coefficient (SC), cooling load, and airflow, for the two instances of sizing.

Sample two selected from the expert staff and authors as HPG through the site visit achieved an optimum connection between the privacy quality for the patient in the diagnosing process and a good feeling resulting from the outdoor daylight and outside landscape. The colors of sample two as HPG matched the façade's finish, and included two colors: medium beige and dark brown as seen in Figure 5. Sample two as HPG is consider as the guideline in glazing elements in healthcare construction, which adapt with healing, engineering requirements, and satisfaction for the patient. Since the project is under construction, the study proved that the cost of the supply and application of sample two, for the whole building, does not exceed the tender price and does not make the contract unbalanced. Sample two as HPG can contribute to achieving a sustainable 19 points in LEED for Healthcare 2009 [60] according to the following.



	A	B	C	D	E	F
4	COOLING LOAD CAPACITY FOR DIFFERENT GLASS TYPES (MAIN HOSPITAL- ROOM EI-WD-0260)					
5–6	SN	GLASS	U Value	SC (Shading Coefficient)	B01 Room Cooling Load	Air flow
7	1	Project specifications	2.5	0.3	5.5 KW	269 L/S
8	2	Sample 2	1.7	0.2	4.8 KW	228 L/S
9		U VALUE IN (W/M2.K)				
10		KW (kilowatt)				
11		L/S (LITER PER SECOND)				

Figure 7. Comparison analysis regarding energy saving, U-value, SC, cooling load, and air flow results.

3.1. Energy and Atmosphere (EA) Category

The study analysis achieved 5 points in optimizing the energy performance credits: regarding the cooling loads required for the air conditioning of the two study rooms mentioned in the table for both the hospital building and the outpatient building, it is clear that changing the quality of the glass prescribed by the specifications of the project to lower U-values and SHGC values leads to reduce the cooling load by 13%, in energy consumption.

3.2. Indoor and Environment Quality (IEQ) Category

The study analysis achieved 2 points in the acoustic environment: sample two as HPG can reduce the external noise by 45 db; 1 point in low-emitting materials: the final material of sample two as HPG is a low-E origin brand that contains a non-VOC; 5 points in daylight and views: the final material of sample two as HPG provides a light transmittance of 18% from a 4.32 m^2 window area, which is compatible with the international sustainability standard, providing a wide vision and connection to the external landscape, as well as preserving the needed privacy for the patient within the diagnosing process; 1 point in indoor chemical and pollutant source control: the final material of sample two was manufactured as antibacterial glass; 1 point in thermal comfort system controllability: sample two as HPG can result in energy saving—as an example, the cooling load reduction reaches approximately 13%, which affects the total energy reduction for the whole building.

3.3. Materials and Resources (MRs) Category

The study analysis achieved 4 points in sustainability regarding sourced materials and products: all components of sample two as HPG that were raw material components came from mines less than 800 km away; furthermore, they are highly capable of being recycled and are fire-resistant. The study with numerical analysis using HAP software achieved significant advanced results regarding retrofit processes for specific façade elements in the ongoing project, focusing on achieving a high ranking in the sustainability rating system, which supports creating a healthy environment for patient wellbeing in healthcare projects located in difficult desert environments. The study supports the decision maker with robust results in energy saving based on the specifications comparison between actual samples carried out by an expert committee. The selected specifications can be addressed in the local Saudi construction codes and regulations for healthcare construction projects, and present pioneering actual specifications for high-performance glazing adopted with an international sustainable rating system.

4. Conclusions

High-performance glazing (HPG) elements are inevitable for all healthcare construction projects and international glass manufacturer investments, which contribute through their research centers to glass quality improvement, green hospitals, and all sustainability standards. This study was based on the installation of three actual samples in a healthcare case study project that were manufactured and erected on site for a comparison process carried out by an expert committee according to achieving results in sustainability impacts and energy saving. The study drew up these recent improvements and classified them according to LEED for Healthcare 2009 in the form of a practical and applicable compatible elements matrix that contributes to supporting healthcare sustainability credits, green hospitals requirements, and the patient's well-being. The study used this compatible elements matrix for a technical analysis comparison process to explore the sustainable impacts and ranking of the three actual HPG sample specifications in the healthcare case study project. The study used HAP software as an energy design, zone sizing, and comparison tool for the technical specifications of the three actual samples to register the energy impacts and savings. The selected sample specification achieved a 13% reduction in the cooling load and a 15% reduction in the air flow needed for cooling energy, contributing with 19 potential points in the LEED Healthcare rating system in three categories (energy and atmosphere (EA), indoor and environment quality (IEQ), materials and resources (MRs)), compatible with EN and the NFRC standard. The selected sample supports the high privacy level needed for patient healing, achieves a contract cost balance, and matches its color with that of the facade elements. The selected sample specifications could be addressed in local healthcare construction project codes and regulations as HPG window specifications in such an environment.

5. Limitations and Future Research Directions

The current study focused on a technical analysis for high-performance glazing and the LEED for Healthcare rating system as a retrofit approach toward energy conservation and asset management inside public organizations buildings, i.e., hospitals, using an analysis approach toward energy consumption inside a university hospital as a case study. The results may be limited to other public spaces of the same context. The study also opens the door for future research studies on public organization building in relation to sustainability, such as the indoor air quality. Future research could also address the conflicting goals of the window manufacturers, such as a greater living comfort at the expense of poorer recyclability, in order to ensure the production of HPG. Additionally, the economic impacts of new technology in sustainable building features can be another interesting area of research.

Author Contributions: Conceptualization, E.M.H.I. and A.E.E.S.; methodology, E.M.H.I.; software, E.M.H.I.; validation, E.M.H.I. and A.E.E.S.; formal analysis, E.M.H.I.; investigation, E.M.H.I. and A.E.E.S.; resources, E.M.H.I. and A.E.E.S.; data curation, E.M.H.I.; writing—original draft preparation, E.M.H.I. and A.E.E.S.; writing—review and editing, E.M.H.I. and A.E.E.S.; visualization, E.M.H.I.; supervision E.M.H.I.; project administration, E.M.H.I.; funding acquisition, E.M.H.I. and A.E.E.S. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia [Project No. GRANT3368].

Institutional Review Board Statement: Not applicable.

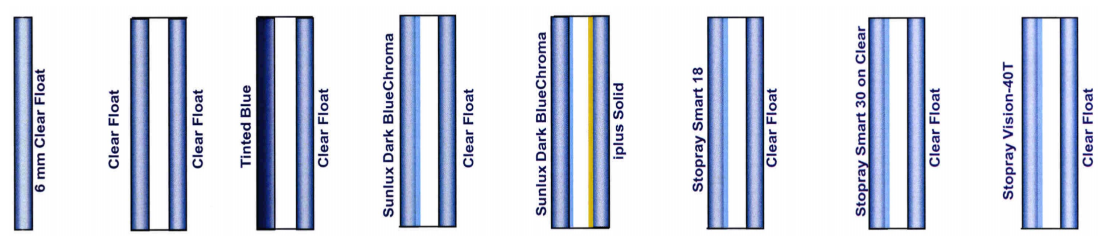
Informed Consent Statement: Not applicable.

Data Availability Statement: Data available upon request from the first author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

U Factor summer, SHGC & RHG



LT	=39	=81	=52	=14	=12	=18	=30	=40
LR int	=3	=14	=13	=15	=12	=16	=15	=15
U-Factor	=5.27	=2.75	=2.75	=2.30	=1.56	=1.32	=1.4	=1.29
SHGC	=0.87	=078	=0.44	=0.22	=0.18	=0.15	=2	=0.20
RHG	=671	=584	=337	=180	=141	=121	=0.22	=154

Figure A1. Technical performance comparison between clear and tinted glass.

Crystalline blind to generate 100W/H/M²

Transparent coating generates 4–28 w/h/m²

Using crystalline glass to generate 100w/h/m²

Thin film as generates 25–50w/h/m²

Figure A2. Using crystalline and amorphous material and coating to generate power.

Observed reduction bacteria after 24 hours results

99% fewer bacteria in:

S. Aureus:

E. Coli:

P. Aeruginosa:

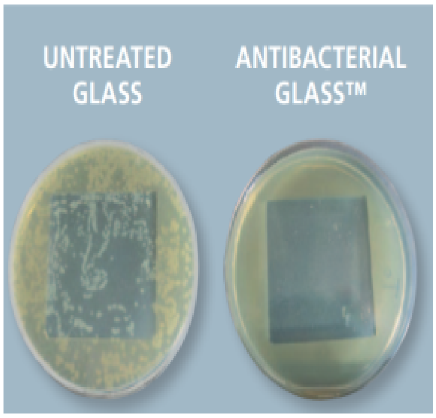


Figure A3. Coating glass supports the antibacterial glass process.

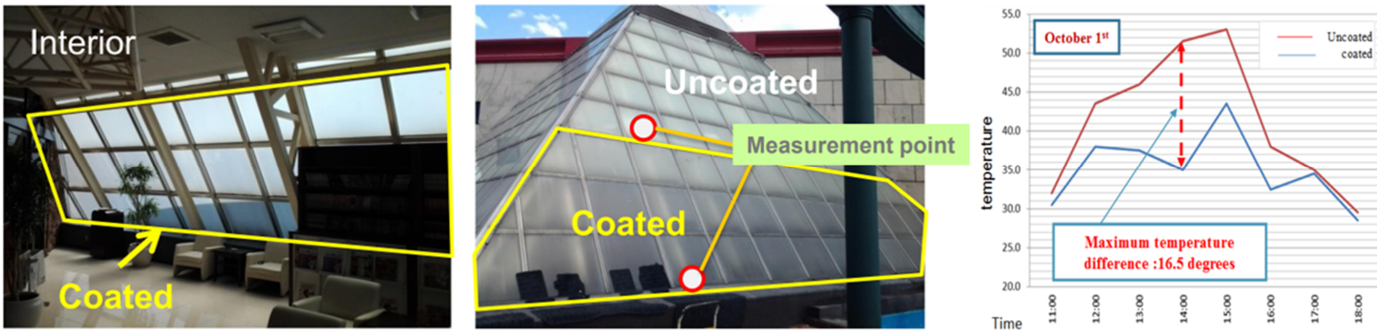


Figure A4. Job reference with transparent coating tested in lab.

Structural glazing | Unitized curtain wall | Structural fixed | Photovoltaic and thin film integrated with curtain wall

Figure A5. Different types of integrated window-and-curtain-wall structures with thin and photovoltaic film in visible light transmittance.

Appendix B

Zone Sizing Summary for FAN COIL (PROJECT SPECIFICATIONS

Project Name: Glass load comparison (B01) 05/06/2021
Prepared by: ZFP 09:40AM

Air System Information

Air System Name . FAN COIL (PROJECT SPECIFICATIONS
Equipment Class .... TERM
Air System Type 4P-FC

Number of zones 1
Floor Area .... 29.0 m²
Location .... AL AHSA, Saudi Arabia

Sizing Calculation Information

Zone and Space Sizing Method:

Zone L/s .... Sum of space airflow rates
Space L/s .... Individual peak space loads

Calculation Months .... Jan to Dec
Sizing Data .... Calculated

Zone Sizing Data

Zone Name	Maximum Cooling Sensible (kW)	Design Air Flow (L/s)	Minimum Air Flow (L/s)	Time of Peak Load	Maximum Heating Load (kW)	Zone Floor Area (m²)	Zone L/(s-m²)
Zone 1	3.5	269	269	Jul 1500	0.8	29.0	9.29

Terminal Unit Sizing Data - Cooling

Zone Name	Total Coil Load (kW)	Sens Coil Load (kW)	Coil Entering DB / WB (°C)	Coil Leaving DB / WB (°C)	Water Flow @ 8.0 °K (L/s)	Time of Peak Load
Zone 1	5.5	3.7	25.1 / 19.1	13.6 / 13.1	0.16	Jun 1600

Terminal Unit Sizing Data - Heating, Fan, Ventilation

Zone Name	Heating Coil Load (kW)	Heating Coil Ent/Lvg DB (°C)	Htg Coil Water Flow @15.0 °K (L/s)	Fan Design Airflow (L/s)	Fan Motor (BHP)	Fan Motor (kW)	OA Vent Design Airflow (L/s)
Zone 1	0.8	20.8 / 23.4	0.01	269	0.000	0.000	52

Space Loads and Airflows

Zone Name / Space Name	Mult.	Cooling Sensible (kW)	Time of Load	Air Flow (L/s)	Heating Load (kW)	Floor Area (m²)	Space L/(s-m²)
Zone 1							
EI-WD-0260 (PROJECT)	1	3.5	Jul 1500	269	0.8	29.0	9.29

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Figure A6. Zone sizing summary for tender specifications of fan coil.

Zone Sizing Summary for FAN COIL (SAMPLE 2)

Project Name: Glass load comparison (B01) 05/06/2021
Prepared by: ZFP 09:48AM

Air System Information

Air System Name .... FAN COIL (SAMPLE 2)
Equipment Class .... TERM
Air System Type 4P-FC

Number of zones 1
Floor Area .... 29.0 m²
Location .... AL AHSA, Saudi Arabia

Sizing Calculation Information

Zone and Space Sizing Method:

Zone L/s .... Sum of space airflow rates
Space L/s .... Individual peak space loads

Calculation Months .... Jan to Dec
Sizing Data .... Calculated

Zone Sizing Data

Zone Name	Maximum Cooling Sensible (kW)	Design Air Flow (L/s)	Minimum Air Flow (L/s)	Time of Peak Load	Maximum Heating Load (kW)	Zone Floor Area (m²)	Zone L/(s-m²)
Zone 1	3.0	228	228	Jul 1500	0.7	29.0	7.86

Terminal Unit Sizing Data - Cooling

Zone Name	Total Coil Load (kW)	Sens Coil Load (kW)	Coil Entering DB / WB (°C)	Coil Leaving DB / WB (°C)	Water Flow @ 8.0 °K (L/s)	Time of Peak Load
Zone 1	4.8	3.1	25.4 / 19.6	13.9 / 13.4	0.14	Jul 1500

Terminal Unit Sizing Data - Heating, Fan, Ventilation

Zone Name	Heating Coil Load (kW)	Heating Coil Ent/Lvg DB (°C)	Htg Coil Water Flow @15.0 °K (L/s)	Fan Design Airflow (L/s)	Fan Motor (BHP)	Fan Motor (kW)	OA Vent Design Airflow (L/s)
Zone 1	0.7	20.7 / 23.4	0.01	228	0.000	0.000	52

Space Loads and Airflows

Zone Name / Space Name	Mult.	Cooling Sensible (kW)	Time of Load	Air Flow (L/s)	Heating Load (kW)	Floor Area (m²)	Space L/(s-m²)
Zone 1							
EI-WD-0260 (SAMPLE 2)	1	3.0	Jul 1500	228	0.7	29.0	7.86

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Figure A7. Zone sizing summary for fan coil when choosing alternative sample two.

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