

Climate-responsive environmental performance assessment of a public administrative building in a humid mediterranean context: An high quality environmental based case study from Morocco

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ABSTRACT

This study presents a comprehensive environmental evaluation of the new headquarters of the Urban Agency of Kenitra to replace by Agency of Kenitra Sidi Kacem Sidi Slimane, Morocco, based on the principles of the high quality environmental (HQE) framework. The building, located in the humid Mediterranean climate of the Gharb region, incorporates a set of architectural, thermal, and operational strategies designed to enhance sustainability and energy efficiency. Using data extracted from the official environmental notice and technical documentation, the analysis examines bioclimatic design measures, the performance of the thermal envelope, HVAC efficiency, lighting systems, water conservation strategies, and comfort conditions. Results indicate that the building achieves high energy performance through a compact form, façade-oriented solar protection, an efficient three-pipe VRV system, and extensive daylight utilization supported by a central atrium. Water consumption is reduced by more than 50% through hydro-efficient sanitary fixtures, while a Class A building management system ensures continuous optimization of HVAC and lighting operations. Municipal infrastructure limits waste management potential, but the overall project demonstrates strong replicability for sustainable public buildings in Morocco. The findings highlight both the strengths and contextual limitations of implementing international certification frameworks in developing contexts and provide insights for future climate-responsive architectural design in the region.

Keywords: sustainable architecture, certification, bioclimatic design, energy efficiency, Urban Agency of Kenitra.

INTRODUCTION

The building sector represents one of the major contributors to global energy consumption and greenhouse gas emissions, as it accounts for about 30–40% of total final energy consumption and nearly 37% of total energy-related CO₂ emissions globally (Abo Elenien et al., 2015). Moreover, the embodied carbon associated with building materials also contributes significantly to the environmental impact of buildings (Boumlik et al., 2024a). As the effects of climate change are increasing regional climatic changes, it is no longer possible to address building performance

based on general principles of sustainability. Instead, building performance must be ensured by developing climate-responsive building design strategies based on regional environmental conditions (Al-Hadhrami, 2013). This is particularly important in Mediterranean climates, where buildings are exposed to high solar radiation, seasonal humidity changes, and increased risk of overheating. These factors create complex relationships between building envelope performance, ventilation strategies, and indoor environmental quality (Hameidia and Medjerabe, 2025). Although there have been many studies on sustainable building design, there is still a significant

gap in the integration of climate-responsive building solutions that address humidity changes and overheating risks in Mediterranean climates.

In line with these international climate change commitments, including the Paris Agreement, Morocco has been increasingly overhauling its environmental and construction regulations under its National Strategy for Sustainable Development (SNDD) policy (Iacobuță et al., 2022). As part of this process, environmental certification systems have started being implemented in large-scale public buildings and tertiary buildings as part of their environmental performance improvement strategies. Among these, high quality environmental (HQE) buildings has started attracting more interest due to its multi-criteria evaluation of buildings' energy performance, indoor environmental quality, water management, and life cycle (Bidou, 2006). However, it should be noted that the implementation of HQE is still very low in Morocco, mainly implemented for flagship projects rather than being an overarching national practice. Moreover, there is still a lack of peer-reviewed studies on the assessment of the environmental performance of HQE buildings, especially under Mediterranean climate conditions that often involve fluctuations in humidity levels and overheating risks. Existing research has mainly been focusing on regulatory alignment and certification mechanisms rather than post-design performance or adaptability under different climates (Boumlik et al., 2024b). This raises critical questions regarding the effectiveness of these internationally developed frameworks in adequately responding to local environmental constraints and climatic realities.

The new headquarters of the Urban Agency of Kenitra (Agency of Kenitra–Sidi Kacem–Sidi Slimane) represents one of the early public administrative buildings in Morocco designed according to HQE environmental certification principles. Located in the Gharb plain, a humid Mediterranean zone characterised by high atmospheric moisture, moderate seasonal thermal variations, and strong Atlantic winds (Soares et al., 2021), the project offers a relevant case for analysing climate-responsive sustainability strategies. Its selection as a case study is justified by its institutional scale, alignment with Moroccan thermal regulations (RGCPÉB), and the integration of bioclimatic design measures, high-performance envelope systems, and

water-efficiency strategies to improve environmental performance (Gargab et al., 2025).

While previous studies have examined isolated aspects of sustainable buildings, such as thermal performance optimization, daylighting efficiency, or renewable energy integration, comparatively fewer investigations have adopted an integrated multi-domain assessment approach in humid Mediterranean climates (Hafez et al., 2023). Moreover, the alignment between architectural design intent and measurable operational performance remains insufficiently explored in developing-country public infrastructure (Ibrahim et al., 2024).

In particular, there is limited empirical evidence evaluating whether HQE-oriented buildings in Morocco achieve performance outcomes consistent with their certification objectives when subjected to local climatic constraints (Asri et al., 2023). This lack of integrated assessment restricts the transferability of sustainability frameworks across different climatic and regulatory contexts.

The objective of this study is to develop and apply an integrated environmental performance assessment framework to evaluate the climatic adaptability and operational coherence of an HQE-oriented public administrative building located in a humid Mediterranean context.

The study seeks to address the following research questions:

1. To what extent do the implemented architectural and engineering strategies align with HQE performance criteria under local climatic conditions?
2. Does the integration of bioclimatic design, HVAC optimization, and renewable energy systems result in measurable improvements in energy efficiency and indoor environmental quality compared to regulatory baselines (RGCPÉB)?

The working hypothesis is that an integrated HQE-based design approach, when adapted to Morocco's Atlantic-Mediterranean climate, can significantly enhance environmental performance beyond minimum regulatory requirements (environmental performance management of building through HQE certification).

By combining architectural analysis, regulatory thermal assessment, daylight performance evaluation, HVAC system modelling (Mateus and Bragança, 2011), and photovoltaic integration within a unified analytical framework, this

research contributes a context-specific methodological model for assessing sustainable public buildings in developing Mediterranean regions.

METHODS

Regulatory and normative framework

The Moroccan General Construction Regulation on Building Energy Performance (RGCPÉB) [No. 2-13-874, 2014] establishes mandatory thermal performance thresholds for new residential and tertiary buildings. The regulation defines two compliance pathways: (i) a performance-based approach relying on dynamic thermal simulation, (ii) a prescriptive approach based on minimum envelope specifications.

In the present study, the performance-based method was adopted, whereby the annual building energy consumption for thermal comfort (BECTh, kWh/m²·year) was calculated and compared to the maximum allowable value for climate zone Kenitra applicable to tertiary administrative buildings 49 kWh/m²·year.

The reference indoor set-point temperatures defined by RGCPÉB (20 °C for heating season and 26 °C for cooling season) were applied. Envelope thermal transmittance limits (U-values) required for Zone Z1 (the applicable regulatory reference zone for this study, per Table 5) include: external walls ≤ 1.20 W/m²·K, exposed roofs ≤ 0.65 W/m²·K (for TGBV 16–25%), glazing ≤ 5.80 W/m²·K, and floor thermal resistance classified as NE (not required) for this zone (Table 5).

Thermal simulations were conducted using DesignBuilder software (v5.5.2.007), with daylighting analysis using the Radiance ray-tracing engine integrated within the same platform, in accordance with regulatory modeling procedures referenced in the RGCPÉB methodological annex.

Climatic zoning and degree-day method

To ensure that thermal performance requirements accurately reflect Morocco's climatic diversity, a national climatic zoning system was developed based on long-term meteorological data and thermal simulation analyses (Merini et al., 2019).

Hourly climatic records from 37 meteorological stations distributed across the country were analyzed over a 10-year period (1999–2008). These data formed the basis for: annual simulations of

heating and cooling energy needs for representative building typologies; evaluation of regional climatic severity indices; and stratification of the national territory into zones with homogeneous thermal behavior (Hänsel et al., 2016). The zoning methodology relies on the concept of degree-days, widely used in building energy assessments (Omarov et al., 2023). Heating degree-days (HDD) were calculated according to:

$$HDD = \sum (T_{base} - T_{mean,i}), \quad \text{for } T_{mean,i} < T_{base} \quad (1)$$

where: $T_{base} = 18$ °C and $T_{mean,i}$ represents the daily mean outdoor temperature.

Cooling degree-days (CDD) were computed analogously using a base temperature of 21 °C. Using HDD and CDD indices, Morocco was split into six climate zones (Zone 1 to Zone 6), each with its own unique thermal properties. According to the national climatic zoning system, Kenitra is classified under Climate Zone Z2 (Tanger reference zone), characterised by a moderate Atlantic-Mediterranean thermal regime with an annual mean temperature of 17.5 °C, monthly values ranging from 11.8 °C in January to 23.0 °C in August, and a relative humidity averaging 81.3% annually. The corresponding regulatory BECTh threshold for tertiary administrative buildings in Zone Z2 is 49 kWh/m²·year (Table 1).

Degree-day calculations were performed using Meteororm version 7.2, which provides typical meteorological year (TMY) datasets generated through stochastic interpolation of long-term ground station and satellite data, based on hourly meteorological records for the period 1986–2005 at the Kenitra site (34.26° N, –6.58° W, 31 m a.s.l., WGS84). This classification ensures that the thermal performance requirements set by the regulation are aligned with the actual climatic and building design conditions of the region. The spatial distribution of the six climatic zones is illustrated in Figure 1 (Boumlik et al., 2024c).

Site location and climatic data

The study site corresponds to the headquarters of the Agency of Kenitra–Sidi Kacem–Sidi Slimane, located in northwestern Morocco at a latitude of 34.26° N, a longitude of –6.58° W, and an average altitude of 31 m above sea level (WGS84 reference system). These coordinates provide an accurate spatial characterisation of

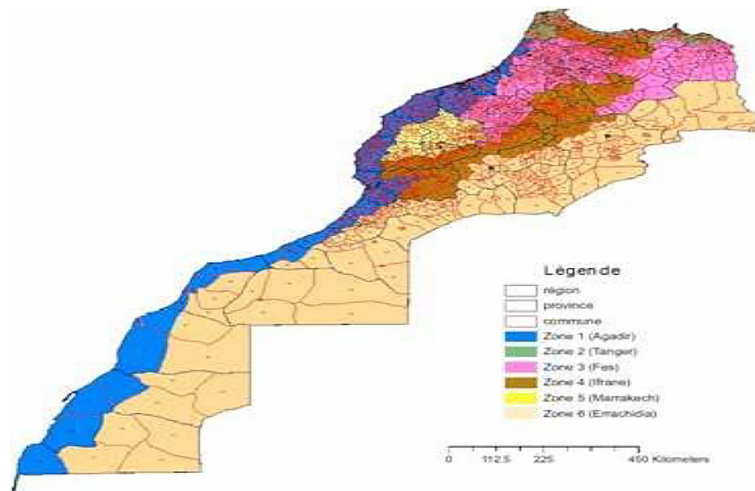


Figure 1. Climatic zoning map of Morocco, which serves as a methodological reference for energy-performance assessment and regulatory compliance in building design

the site and constitute essential baseline information for both solar trajectory modelling and photovoltaic assessments, as latitude governs the solar path while altitude and geographical location influence local climatic conditions (Luis-Ruiz et al., 2024).

Climatic data were extracted from Meteonorm version 7.2, which provides typical meteorological year datasets generated through stochastic interpolation of long-term ground station and satellite data (Huld et al., 2018), Meteonorm v7.2 Handbook, Meteotest AG, Bern, Switzerland. The dataset corresponds to the period 1986–2005 with a data coverage rate of 100%, and includes hourly values of global horizontal irradiation, diffuse irradiation, ambient temperature, wind

speed, relative humidity, and Linke turbidity index, as summarised in Figure 2.

Global horizontal solar irradiation exhibits a marked seasonal variation, with minimum values of 2.76 kWh/m²·day in December and 2.97 kWh/m²·day in January, and peak values of 7.73 kWh/m²·day in June and 7.78 kWh/m²·day in July. The annual average of 5.37 kWh/m²·day confirms substantial solar resource availability throughout the year. Diffuse horizontal irradiation averages 1.66 kWh/m²·day annually, ranging from 0.87 kWh/m²·day in December to 2.22 kWh/m²·day in May–June, indicating that a non-negligible fraction of solar radiation remains exploitable even under overcast conditions (Chaich et al., 2024). The annual mean ambient temperature

Site Kenitra (Maroc)						
Source des donnr Meteonorm 7.2 (1986-2005), Sat=100%						
	Irradiation globale horizontale	Irradiation diffuse horizontale	Température	Vitesse du vent	Linke Turbidity	Relative Humidity
	kWh/m ² ·jr	kWh/m ² ·jr	°C	m/s	[]	%
Janvier	2.97	1.02	11.8	2.50	2.863	84.4
Février	3.72	1.35	12.9	2.70	2.933	83.8
Mars	5.23	1.74	14.9	2.99	3.205	80.4
Avril	6.38	2.06	15.7	3.40	3.269	80.8
Mai	7.15	2.22	18.3	3.40	3.572	78.8
Juin	7.73	2.22	21.2	3.20	3.791	78.7
Juillet	7.78	2.09	22.8	3.19	4.302	78.8
Août	7.08	2.01	23.0	3.00	3.892	81.8
Septembre	5.69	1.78	21.4	2.91	3.629	82.3
Octobre	4.42	1.50	19.4	2.79	3.333	81.5
Novembre	3.38	1.08	15.1	2.80	2.933	82.3
Décembre	2.76	0.87	13.4	3.09	2.790	82.2
Année	5.37	1.66	17.5	3.0	3.376	81.3
Irradiation globale horizontale variabilité d'une année sur l'autre 3.3%						

Figure 2. Monthly average climatic parameters for Kenitra (Morocco) derived from Meteonorm 7.2 (1986–2005)

is 17.5 °C, with monthly values ranging from 11.8 °C in January to 23.0 °C in August, reflecting a moderate Atlantic-Mediterranean thermal regime with limited seasonal extremes. Mean annual wind speed is approximately 3.0 m/s with limited seasonal variability (Dabbous et al., 2025). The Linke turbidity index presents an annual mean of 3.376, increasing progressively from winter to summer, while relative humidity remains high and stable throughout the year, with an annual average of 81.3%.

The apparent solar trajectory shown in Figure 3 was generated using DesignBuilder (v5.5.2.007), based on astronomical algorithms derived from the solar position calculations integrated within the EnergyPlus simulation engine (Energy Plus Engineering Reference, U.S. Department of Energy).

A precise understanding of the apparent solar motion at a given geographical location is essential for the design and optimization of solar energy systems (Fennane et al., 2026). The position of the sun in the sky is described by two angular parameters: the solar altitude angle α , defined as the angle between the sun’s rays and the horizontal plane, and the solar azimuth angle A_Z , defined as the angular deviation of the sun from the south direction, measured negatively toward the east (de Luis et al., 2024). These are computed from the following standard astronomical expressions:

$$\sin(\alpha) = \sin(\varphi) \cdot \sin(\delta) + \cos(\varphi) \cdot \cos(\delta) \cdot \cos(\omega) \quad (2)$$

$$\cos(A_Z) = [\sin(\alpha) \cdot \sin(\varphi) - \sin(\delta)] / [\cos(\alpha) \cdot \cos(\varphi)] \quad (3)$$

where: φ is the site latitude (34.26° N), δ is the solar declination angle (varying between -23.45° and +23.45° over the year), and ω is the hour angle (15° per hour from solar noon, negative in the morning).

The solar declination is given by:

$$\delta = 23.45^\circ \cdot \sin[360/365 \cdot (284 + n)] \quad (4)$$

where: n is the day of the year.

Figure 3 illustrates the apparent solar trajectory for the Kenitra site, represented as solar altitude versus azimuth across characteristic days of the year (Zahra et al., 2025). The diagram was generated using DesignBuilder (v5.5.2.007) with the EnergyPlus solar position engine, based on hourly time steps (60-minute intervals) applied consistently throughout the annual dynamic thermal simulation. The diagram clearly shows the seasonal shift in solar height and path length, from low winter sun arcs to high summer trajectories, providing the geometric basis for determining optimal photovoltaic panel orientation (south-facing, 32° tilt) and inclination adopted in this study.

Shading analysis was conducted within the DesignBuilder environment using the full three-dimensional building model. Obstructions from adjacent built volumes and envelope shading elements including the building’s overhangs and façade projections were explicitly modelled, and their impact on direct solar irradiation at each façade and roof surface was assessed across the full simulation year. The results informed both the daylight factor calculations and the sizing of the photovoltaic system, confirming that the selected roof areas are free from significant inter-row and obstruction shading.

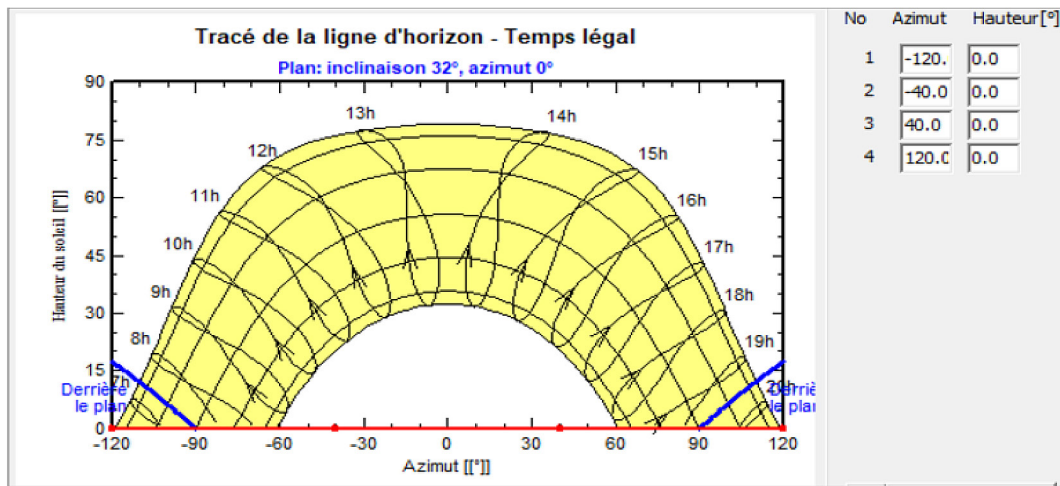


Figure 3. Apparent solar trajectory at the Kenitra site expressed as a function of solar altitude and azimuth

Thermal performance assessment method

Moroccan thermal regulations (RGCPÉB/RTCM) define a series of minimum performance levels in buildings by means of two compliance routes: a performance route, in which annual heating/cooling requirements are calculated by means of dynamic simulation, using reference indoor temperature limits (20 °C heating season, 55% RH; 26 °C cooling season, 60% RH), comparing calculated BECTh (building energy consumption for thermal comfort, in kWh/m²·year) with maximum allowable limits in terms of climatic zone and building type; and a prescriptive route, in which compliance with a series of minimum thermal envelope specifications is mandatory. For this study, in which a calculated glazing to building envelope area ratio (TGBV) of 43.35% was found, as it was below the threshold of 45%, above which the performance route is mandatory, the prescriptive route was adopted to define the minimum thermal envelope requirements, ASHRAE 90.1 being adopted as a reference to calculate primary energy gain of all end-uses (HVAC, lighting, DHW). The BECTh limits by climatic zone and building type are as follows (Table 1).

Building description

The case study building is the new headquarters of the Agency of Kenitra–Sidi Kacem–Sidi Slimane (AUKSS), a multi-storey public administrative building comprising a basement (sous-sol), ground floor (RDC), mezzanine, and three upper levels (R+1, R+2, R+3), located on Lot A2 in Kenitra, northwestern Morocco (34°30' N, 6°60' W, altitude 5 m). The total conditioned floor area is 4,394 m², distributed across office spaces, meeting rooms (salles de réunion), a multipurpose hall (salle polyvalente), IT rooms (salle informatique), a media library (médiathèque), cafeteria, sanitary areas, and circulation zones.

The building features a compact form organised around a central open patio, with the principal façade and north-facing spaces housing the primary occupied offices, meeting rooms, and media library. South-facing spaces rely on assisted natural ventilation, while north-facing zones are served by a mechanical VRF system. The 3D thermal model was built in DesignBuilder (v5.5.2.007) on the basis of architectural plans (DWG format, plan Veritas 02-05-19), with high geometric precision to accurately reflect the as-designed building form, façade orientations, and shading elements.

The three-dimensional thermal model of the building, as implemented in DesignBuilder, is illustrated in Figure 4. The model captures the compact massing, the orientation-specific façade treatment – with highly glazed north and west elevations contrasting with the minimally glazed south rear façade – and the roof configuration integrating skylights, mechanical systems, and photovoltaic panel zones. These geometric features were reproduced with high fidelity to ensure accurate representation of solar exposure, shading interactions, and heat transfer through the building envelope in the dynamic simulation.

Envelope characteristics

The building envelope was designed to comply with RTCM Zone 1 prescriptive requirements for a TGBV of 36–45%, as established by the Bureau Veritas thermal simulation report (STD Version 0, December 2019). The opaque wall assembly consists of a reinforced concrete structural frame with a traditional double-brick infill (150 mm brick + 50 mm rockwool insulation + 70 mm brick), yielding an achieved external wall U-value of 0.409 W/m²·K (regulatory limit: ≤ 1.20 W/m²·K). The roof assembly comprises a 200 mm hollow-block slab (hourdis), 40 mm

Table 1. Specific annual heating and cooling requirements of buildings in Morocco

Maximum annual specific heating and cooling requirements of buildings in Morocco in kWh/m ² /year					
Zones	Residential	Education	Health	Tourism	Other (**)
Z1 (Agadir)	40	44	72	48	45
Z2 (Tanger)	46	50	73	52	49
Z3 (Fes)	8	61	68	66	49
Z4 (Ifrane)	64	80	47	34	35
Z5 5 (Marrakech)	61	65	92	88	56
Z6 (Errachidia)	65	67	93	88	58

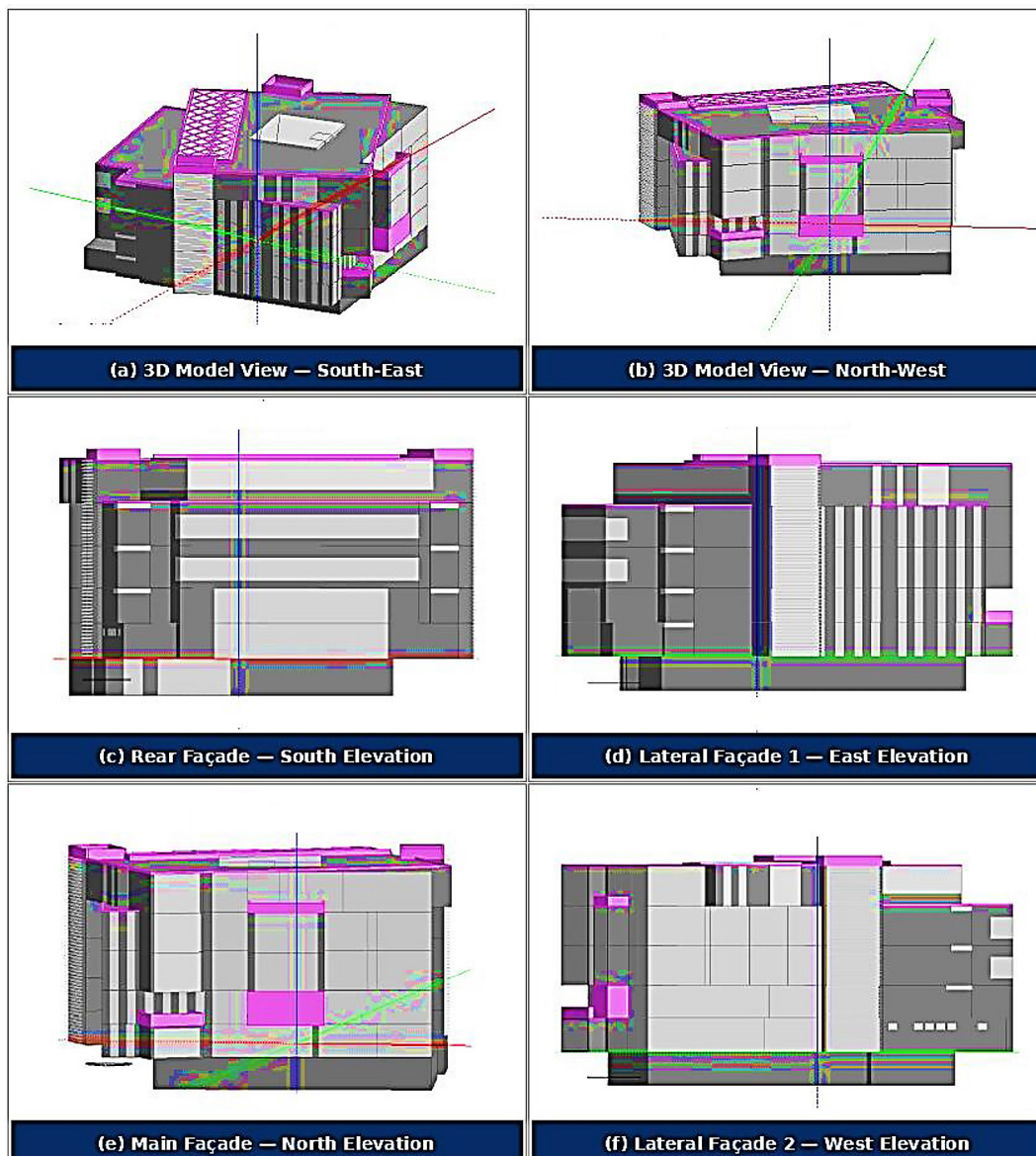


Figure 4. Three-dimensional DesignBuilder simulation model of the AUKSS building (Kenitra, Morocco): (a) south-east view, (b) north-west view, (c) south rear elevation, (d) east lateral elevation, (e) north main façade, (f) west lateral elevation

reinforced concrete screed, 40 mm expanded cork insulation, and 10 mm tiling, achieving a roof U-value of $0.50 \text{ W/m}^2\cdot\text{K}$ (regulatory limit: $\leq 0.55 \text{ W/m}^2\cdot\text{K}$). The ground floor slab consists of 200 mm reinforced concrete, 50 mm screed, and 7 mm tiling, with a U-value of $2.28 \text{ W/m}^2\cdot\text{K}$ (no regulatory requirement NE for this zone). Internal partition walls are 150 mm blockwork (parpaing) with a U-value of $2.05 \text{ W/m}^2\cdot\text{K}$.

External glazing consists of double-glazed units with a thermal transmittance of $U = 2.5 \text{ W/m}^2\cdot\text{K}$, a solar factor of $FS = 0.70$, and a light transmittance (TLW) of 80%. Interior solar shading (stores intérieures) is installed on south-facing façades to limit direct solar gains and overheating

risk during summer. The TGBV breakdown by façade orientation is: north 70.95%, east 34.19%, south 5.86%, west 62.58%, giving an overall TGBV of 43.35%. Accordingly, the prescriptive requirements applicable under Zone 1, TGBV 36–45% are: roof $U \leq 0.55 \text{ W/m}^2\cdot\text{K}$, external walls $U \leq 1.20 \text{ W/m}^2\cdot\text{K}$, glazing $U \leq 3.30 \text{ W/m}^2\cdot\text{K}$, solar factor $FS \leq 0.70$ (north) / ≤ 0.30 (other orientations). All envelope components meet these thresholds as summarised in Table 2.

Envelope airtightness was set at $1.7 \text{ m}^3/\text{h}/\text{m}^2$ at 4 Pa, consistent with HQE and RT2005 requirements, as provided by the HVAC engineering consultant. No post-construction blower-door test was planned by the client.

Table 2. Regulatory thermal requirements as a function of glazing ratio

Climatic zone	Glazing ratio (TGBV)	U-value of exposed roofs (W/m ² ·K)	U-value of external walls (W/m ² ·K)	U-value of glazing (W/m ² ·K)	Minimum thermal resistance of floors on ground (m ² ·K/W)	Solar factor of glazing FS*
Regulatory climatic zone Z1 (Ref. Agadir)	≤ 15%	≤ 0.75	≤ 1.20	≤ 5.80	NE	NE
	16–25%	≤ 0.65	≤ 1.20	≤ 5.80	NE	North: NE Others: ≤ 0.7
	26–35%	≤ 0.65	≤ 1.20	≤ 3.30	NE	North: NE Others: ≤ 0.5
	36–45%	≤ 0.55	≤ 1.20	≤ 3.30	NE	North: ≤ 0.7 Others: ≤ 0.3

HVAC system modeling

The HVAC baseline system was selected using ASHRAE 90.1-2010 Tables G3.1.1A and G3.1.1B. Based on the conditioned floor area of 4,394 m² and an all-electric energy source, the reference system corresponds to System 6 Packaged VAV with parallel fan-powered (PFP) boxes, comprising air handling units with electric heating coils and direct expansion cooling, with zone-level recirculation boxes equipped with electric reheat batteries.

For the proposed design, north-facing spaces (offices, media library, meeting rooms zones with prolonged occupancy) are served by a three-pipe variable refrigerant flow (VRF/DRV) system, enabling simultaneous heating and cooling with individual zone control. South-facing spaces adopt assisted natural ventilation, combining fresh air supply with mechanical exhaust to reduce cooling loads, with interior shading devices preventing overheating. Cafeteria and sanitary areas use single-flow mechanical extraction (VMC simple flux).

The heating COP of the VRF system was confirmed at 2.36 (heating energy demand: 1,167.51 Wh/m²·year; electricity consumption: 492.34 Wh/m²·year). The cooling COP was confirmed at 2.70 (total cooling load: 11,695.91 Wh/m²·year; electricity consumption: 4,324.54 Wh/m²·year).

Table 3. Air flow rates expressed in air changes per hour (ACH) for different functional spaces

Airflow rate (ACH – air changes per hour)	Space
3 ACH	Offices
3 ACH	Meeting room
6 ACH	Workroom
6 ACH	Multipurpose hall
12 ACH	Computer room
4 ACH	Sanitary area

Indoor thermal comfort set-points are 20 °C / 55% RH (heating season) and 26 °C / 60% RH (cooling season), managed via a centralised BMS with a ±2 °C user-adjustable range and an indoor air velocity limit of ≤ 0.17 m/s.

Fresh air supply rates follow RT2012 standards, differentiated by space function: offices and meeting rooms at 3 ACH, workrooms and multipurpose hall at 6 ACH, IT rooms at 12 ACH, and sanitary areas at 4 ACH (Table 3).

Simulation procedure

Dynamic thermal simulations were performed using DesignBuilder v5.5.2.007 interfaced with the EnergyPlus V8.1 calculation engine (U.S. Department of Energy). The simulation timestep was 10 minutes (6 timesteps per hour), providing high temporal resolution for accurate transient thermal response. Daylighting calculations were conducted using the Radiance ray-tracing engine integrated within DesignBuilder, with a 0.5 × 0.5 m mesh resolution and a CIE Uniform Overcast Sky model.

Meteorological boundary conditions: Hourly TMY data were sourced from the ASHRAE V5.0 database for the Rabat-Salé meteorological station (classified as ASHRAE Zone 3A / RTCM Zone 1), obtained via Meteonorm. The file records 219 hours per year with outdoor dry-bulb temperature ≥ 28 °C. Heating loads were calculated for November–April; cooling loads for May–October. The primary energy conversion factor applied is $f_p = 2.253$ for electricity in Morocco.

Internal gains and schedules – occupancy covers the full year excluding weekends and 16 public holidays, with daily operation from 09:00 to 16:30. Occupancy densities are: offices 0.1 person/m² (120 W/person), meeting rooms 0.3 person/m² (120 W/person), multipurpose hall 0.7 person/m² (120 W/person), based on a metabolic

rate of 58 W/m² (1 MET, sedentary activity). Equipment power densities are: offices and meeting rooms 10 W/m², multipurpose hall 15 W/m², cafeteria 3 W/m². Lighting power density is 7 W/m² (LED, 300 lux target, 2.3 W/m² per 100 lux), with daylight sensor control.

Convergence and validation: All modelling assumptions comply with RTCM, ASHRAE 90.1, and RT2012 standards. The simulation was validated against the HQE sub-target 4.2.1 prerequisite, requiring a minimum 10% energy gain relative to the ASHRAE 90.1 baseline – the model achieved 42% primary energy gain (project: 42.56 kWh/m²; baseline – 73.87 kWh/m²), and a 42% reduction in CO₂ emissions (project: 1.594 kg eq CO₂/m²·year vs. baseline – 2.75 kg eq CO₂/m²·year). Summer thermal comfort was verified against HQE sub-target 8.3.1 (operative temperature > 28 °C for < 3% of occupied hours) – results show 0.03–2% exceedance across all south-facing naturally ventilated spaces, confirming compliance.

RESULTS

Architectural and spatial organization analysis

The architectural rendering of the Agency of Kenitra–Sidi Kacem–Sidi Slimane (AUKSS) building exterior is shown in Figure 5, depicting the compact massing, the curtain wall on the north façade, the wood-panel cladding on the upper levels, and the incorporation of landscaping features that align with the bioclimatic design strategy.



Figure 5. Architectural rendering of the AUKSS building exterior (Kenitra, Morocco), showing the north main façade, curtainwall glazing, upper-level wood cladding, and bioclimatic landscaping integration

The spatial organization of the building across all floor levels was analysed using AutoCAD 2D floor plans reconstructed from the architectural drawings, as illustrated in Figure 6. The four levels exhibit a clear functional evolution from ground to upper floors. The ground floor (RDC) concentrates collective and public-facing functions reception, multipurpose hall, archive, and media library organised around a central open patio that serves as the primary passive daylighting and natural ventilation strategy. The first floor (R+1) transitions toward specialised administrative and meeting functions, with three large rooms benefiting from direct façade exposure and terrace access. The second floor (R+2) represents the highest functional density, accommodating

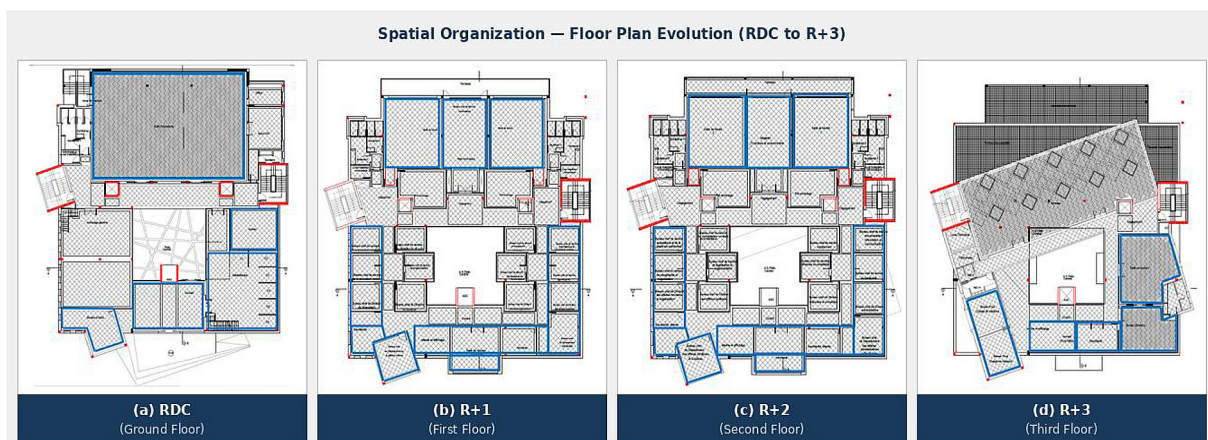


Figure 6. Spatial evolution of the AUKSS building across floor levels: (a) ground floor – RDC, (b) first floor — R+1, (c) second floor — R+2, (d) Third floor — R+3. Floor plans reconstructed in AutoCAD from architectural drawings

numerous office units and meeting rooms distributed symmetrically around the patio. The third floor (R+3) is the most technically specialised, integrating rooftop mechanical systems, skylights, executive offices, and restricted-access service areas. Across all levels, vertical circulation is ensured through staircases and elevators positioned on both sides of the plan, while the patio consistently provides daylighting and cross-ventilation to interior spaces on every floor.

Daylighting simulation results

Natural lighting performance was assessed across all occupied floor levels using the daylight factor (DF) method, computed under a CIE uniform overcast sky with the radiance engine integrated in DesignBuilder. The spatial distribution of DF across the four floor levels is presented in Figure 7, which illustrates the progressive

improvement in daylighting performance from ground floor to upper levels.

As shown in Figure 7a, the ground floor (RDC) exhibits a strong contrast between façade-adjacent zones where high illuminance levels above 1000 lux are represented by red and yellow areas and deeper interior zones where blue and green tones indicate reduced daylight availability. The presence of surrounding built volumes and the central patio’s shading effect limit direct sky exposure at this level, resulting in the lowest overall DF values in the building. At the first floor (R+1), shown in Figure 7b, sky access improves moderately, with façade-facing spaces achieving better DF values while interior patio-adjacent rooms retain intermediate performance. The second floor (R+2), illustrated in Figure 7c, demonstrates a notable increase in compliant area, as reduced external obstructions allow more extensive daylight penetration along the perimeter. The third

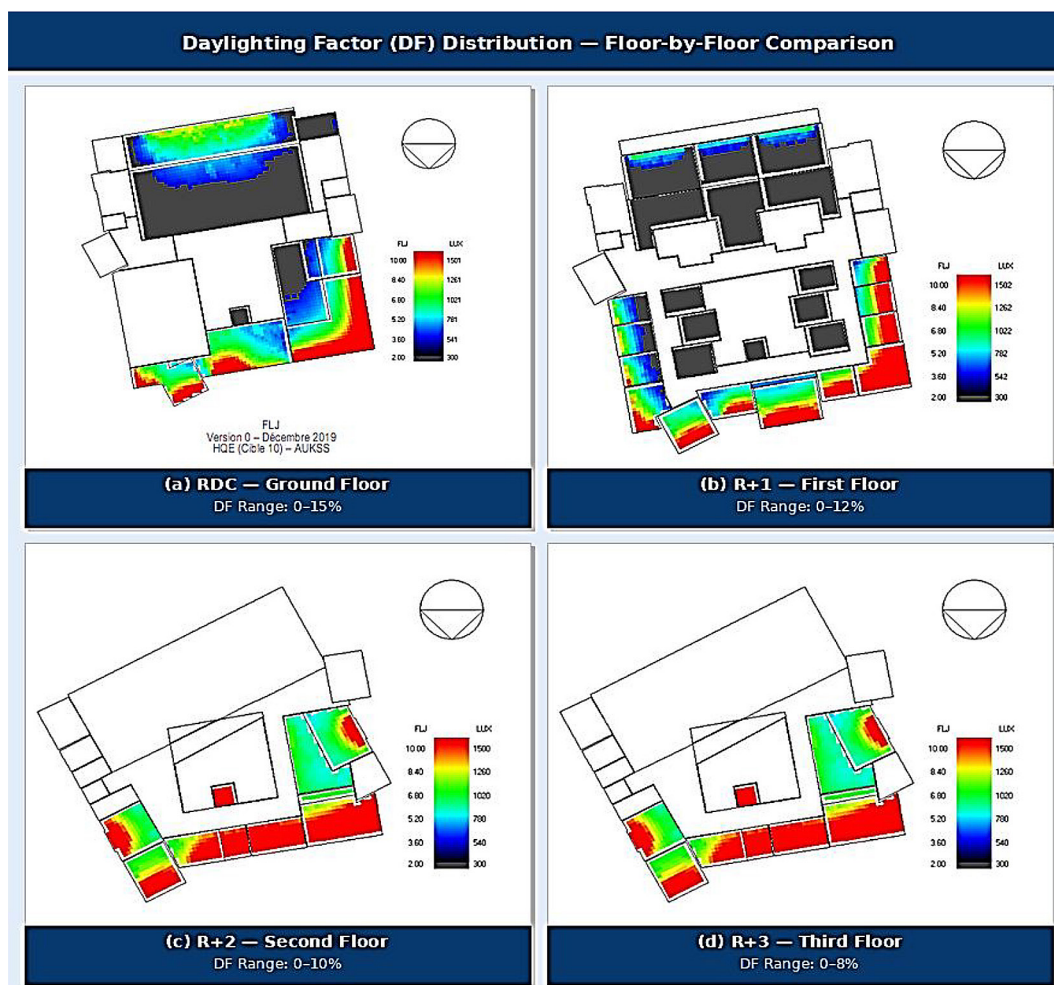


Figure 7. Daylight factor spatial distribution maps across floor levels: (a) RDC — ground floor, (b) R+1 — first floor, (c) R+2 — second floor, (d) R+3 — third floor. Colour scale from blue (low DF) to red (high DF). Simulated using radiance raytracing under CIE uniform overcast sky

floor (R+3), presented in Figure 7d, achieves the best overall daylighting performance, with most façade-facing offices reaching illuminance levels well above regulatory thresholds, while only a limited number of deep interior spaces remain in low-daylight zones.

The quantitative compliance analysis, presented in Figure 8, evaluates the percentage of conditioned floor area meeting each of three DF thresholds $DF \geq 1.2\%$, $DF \geq 2.0\%$, and $DF \geq 2.5\%$ against the regulatory requirement that at least 80% of the reference area must satisfy the minimum criterion. Under the $DF \geq 1.2\%$ threshold, compliance increases progressively from 72% at the ground floor to 94% at the third floor, with upper floors satisfying the 80% regulatory requirement. Under the more demanding $DF \geq 2.0\%$ criterion, compliance ranges from 48% (RDC) to 83% (R+3), with only the upper two floors meeting the regulatory threshold. The strictest criterion, $DF \geq 2.5\%$, results in non-compliance across all floors except R+3, where 72% of the area remains below the threshold. These results confirm that the $DF \geq 1.2\%$ scenario represents the most achievable compliance target under current architectural conditions, while spaces not meeting higher DF thresholds, particularly ground-floor interior offices, will require supplementary artificial lighting to ensure adequate visual comfort.

The findings highlight the decisive influence of floor elevation, façade proximity, and patio geometry on natural lighting availability throughout the building. A summary of compliance levels by threshold is provided in Table 4.

Thermal envelope performance and regulatory compliance

The thermal envelope of the AUKSS building was designed to satisfy the prescriptive requirements of the Moroccan Thermal Building Regulation (RTCM/RGCPÉB), applicable to climate Zone 1 with a glazing-to-building-envelope ratio (TGBV) of 43.35%, which falls within the 36–45% regulatory category. Figure 9 presents the detailed material layer composition of the four principal envelope components as modelled in DesignBuilder and certified by Bureau Veritas.

The external wall, panel (a), consists of seven distinct layers: exterior cement mortar (15 mm), outer brick leaf (150 mm, Brique 12T), rockwool insulation (50 mm), inner brick leaf (70 mm, Brique 8T), and interior cement mortar (15 mm). This assembly achieves a thermal transmittance of $U = 0.409 \text{ W/m}^2\text{-K}$, which is 66% below the regulatory ceiling of $1.20 \text{ W/m}^2\text{-K}$, demonstrating a high-performance wall system that significantly exceeds the minimum requirement. The roof

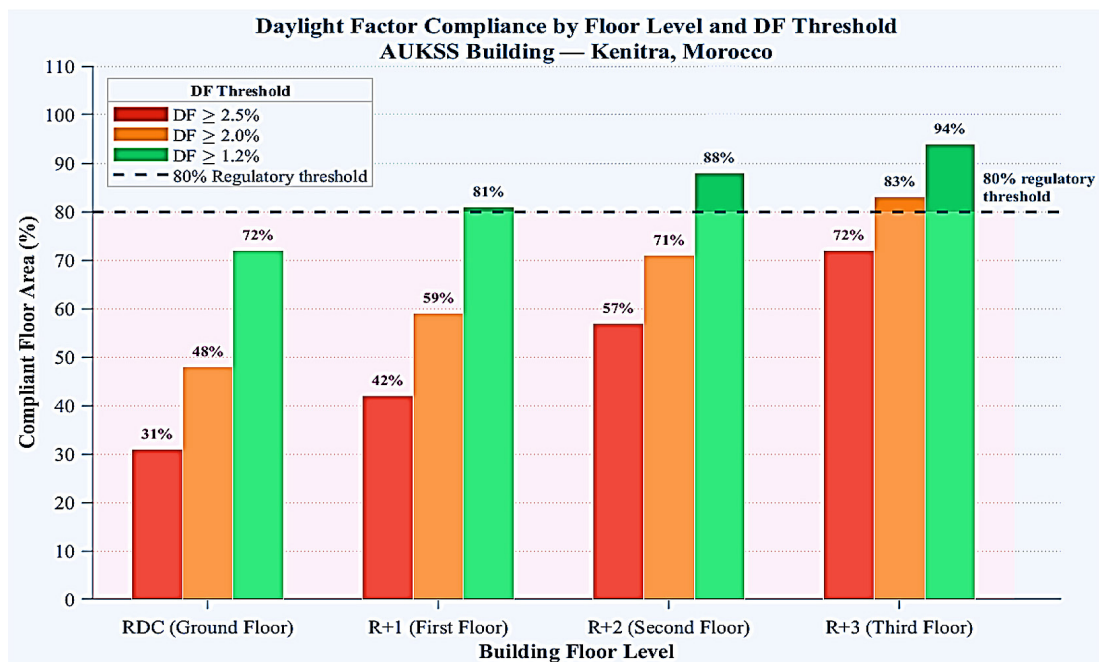


Figure 8. Percentage of compliant floor area per level for three DF thresholds ($DF \geq 1.2\%$, $DF \geq 2.0\%$, $DF \geq 2.5\%$). The dashed line indicates the 80% regulatory compliance threshold required by RGCPEB and HQE framework

Table 4. Summary of daylight factor (DF) compliance levels

DF threshold	Daylight level interpretation	Overall compliance	Regulatory status	Main observation
DF ≥ 2.5%	High daylight / Good visual comfort	Low	Not achieved	Several workspaces show insufficient daylight penetration
DF ≥ 2.0%	Moderate to good daylight	Medium	Partially achieved	Improved performance with the remaining non-compliant areas
DF ≥ 1.2%	Basic acceptable daylight	High	Achieved	Daylight is generally available across most spaces
DF ≥ 2.5%	High daylight / Good visual comfort	Low	Not achieved	Several workspaces show insufficient daylight penetration

assembly, panel (b), comprises tiling (10 mm), screed (10 mm), 40 mm expanded cork insulation, reinforced concrete screed (40 mm), a 200 mm hollow-block slab (hourdis), and a cement mortar finishing layer, achieving $U = 0.50 \text{ W/m}^2\text{K}$

m^2K , 9% below the most stringent limit of $0.55 \text{ W/m}^2\text{K}$ applicable to this TGBV category. The ground floor slab, panel (c), consists of 7 mm tiling, 50 mm screed, a 200 mm reinforced concrete slab, and a 100 mm gravel sub-base, yielding $U =$

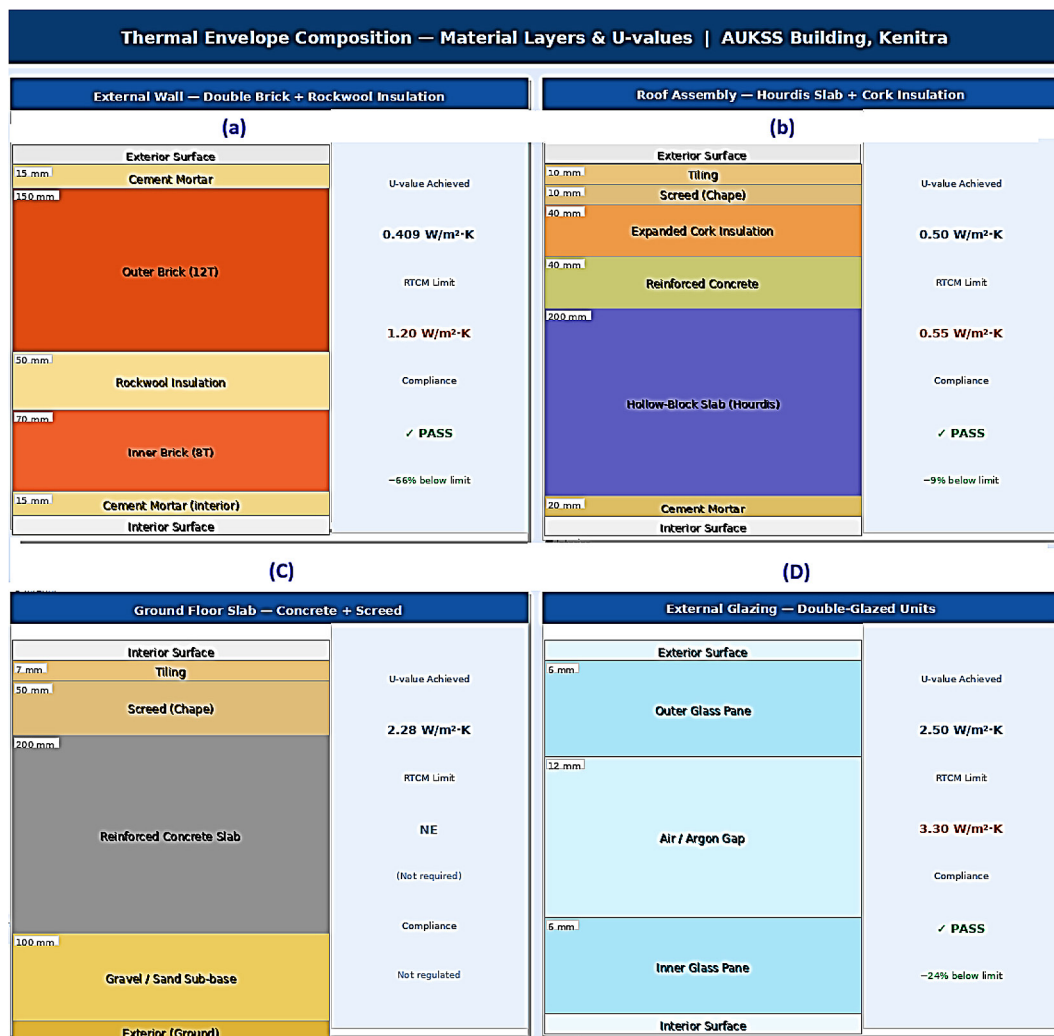


Figure 9. Material layer composition of the AUKSS building thermal envelope. (a) External wall double brick with 50 mm rockwool insulation, $U = 0.409 \text{ W/m}^2\text{K}$; (b) roof assembly hourdis slab with 40 mm expanded cork insulation, $U = 0.50 \text{ W/m}^2\text{K}$; (c) ground floor slab reinforced concrete with screed and tiling, $U = 2.28 \text{ W/m}^2\text{K}$; (d) external glazing double-glazed units with air/argon gap, $U = 2.50 \text{ W/m}^2\text{K}$, FS = 0.70. All U-values in $\text{W/m}^2\text{K}$. RTCM Zone 1, TGBV = 43.35%

2.28 W/m²·K; no regulatory thermal requirement applies to this component under RTCM Zone 1. External glazing, panel (d), uses double-glazed units comprising two 6 mm glass panes separated by a 12 mm air/argon gap, achieving U = 2.50 W/m²·K, 24% below the glazing limit of 3.30 W/m²·K, with a solar factor FS = 0.70 and a light transmittance of 80%.

The quantitative performance comparison across all regulated components is presented in Figure 10. All three regulated components, external wall, roof, and glazing, achieve U-values comfortably below their respective RTCM limits, with the wall showing the largest margin of compliance. The roof insulation operates closest to its regulatory limit, indicating that a modest increase in cork insulation thickness could further strengthen summer thermal resistance in future design iterations. Together, these envelope performance characteristics directly support the 49% overall energy saving demonstrated in Section 5.4, by reducing peak heating and cooling loads and limiting unwanted solar gains through the highly glazed north and west facades.

Building energy performance and operational efficiency

The annual energy simulation results are summarised in Figure 11, which presents the final

energy consumption per end-use category for both the ASHRAE 90.1 baseline and the proposed AUKSS design. The figure shows five grouped bar pairs (blue = baseline, green = project): heating (2,012 vs 447 Wh/m²·yr, -78%), cooling (5,639 vs 3,807 Wh/m²·yr, -32%), auxiliary & ventilation (17,425 vs 7,233 Wh/m²·yr, -58%), lighting (7,719 vs 5,277 Wh/m²·yr, -32%), and total (32,795 vs 16,764 Wh/m²·yr, -49%). The percentage saving for each category is marked directly on the figure with a bidirectional arrow between the two bars.

The dominant saving comes from auxiliary & ventilation, which alone accounts for a reduction of 10,192 Wh/m²·yr (-58%), reflecting the replacement of the centralised ASHRAE System 6 baseline with the zone-level VRF system and assisted natural ventilation on south-facing spaces. Heating achieves the largest percentage reduction (-78%), owing to the mild Kenitra winter climate and the well-insulated envelope. Cooling and lighting each achieve -32%.

To understand why auxiliary & ventilation dominates the saving, Figure 12 disaggregates the total 49% saving into its four end-use contributions. The pie chart (left panel) shows that aux & ventilation accounts for 63.6% of all saved energy, followed by lighting at 15.2%, cooling at 11.4%, and heating at 9.8%. The stacked bar (right panel) confirms the same pattern in absolute terms: the

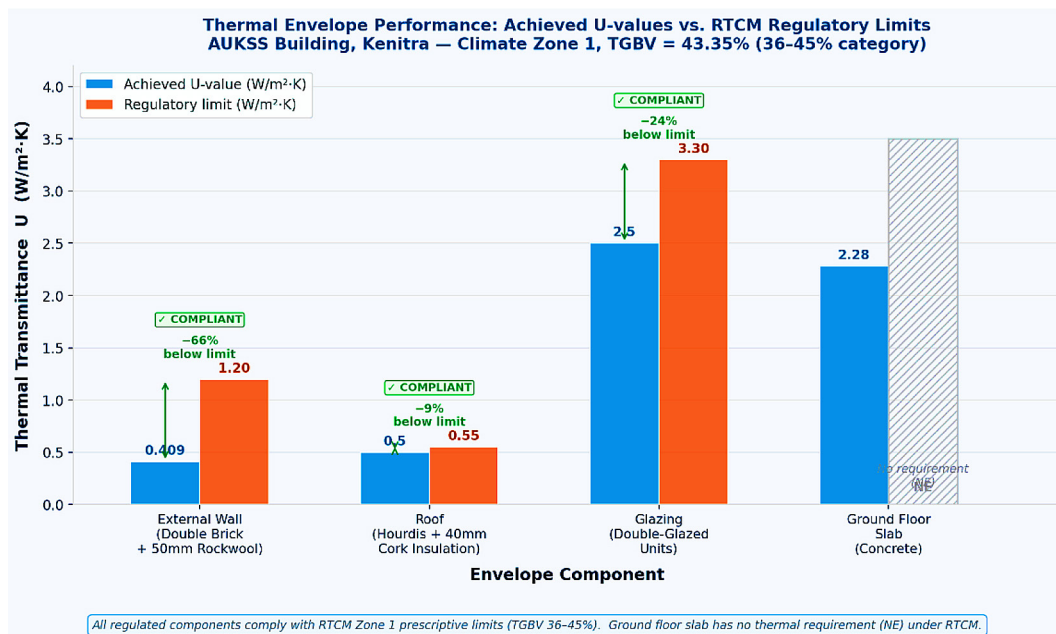


Figure 10. Comparison of achieved thermal transmittance U-values against RTCM/RGCPÉB regulatory limits by envelope component. Climate Zone 1, TGBV = 43.35% (36–45% category). NE = no regulatory requirement. Percentage labels indicate the improvement margin below the applicable regulatory limit

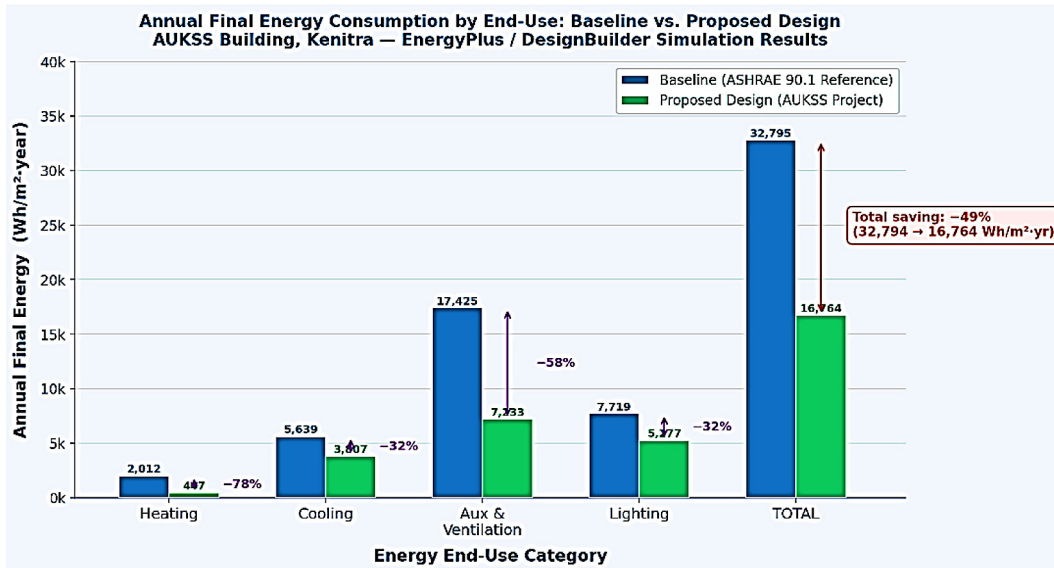


Figure 11. Annual final energy consumption by end-use category: ASHRAE 90.1 baseline (blue) vs. proposed AUKSS design (green)

baseline stack reaches 32,795 Wh/m²-yr, with the green aux & ventilation segment (17,425) being the tallest layer, while the project stack falls to 16,764 Wh/m²-yr, with aux & ventilation reduced to 7,233. The red arrow between the two stacked bars indicates the overall -49% reduction.

The seasonal behaviour behind these annual totals is illustrated in Figure 13, which shows the monthly distribution of cooling demand (upper panel) and heating demand (lower panel) for both baseline and project. In the upper panel, cooling

loads are zero in January–February, begin rising in March–April, peak sharply in July (baseline ~3.450 Wh/m²-month, project ~2.900 Wh/m²-month), and return to near-zero by December. The orange shaded band highlights the cooling season from May to September. In the lower panel, heating loads are concentrated in January–March and November–December, with January showing the highest baseline value (~1.150 Wh/m²-month, reduced to ~280 Wh/m²-month in the project). The blue shaded bands mark the two

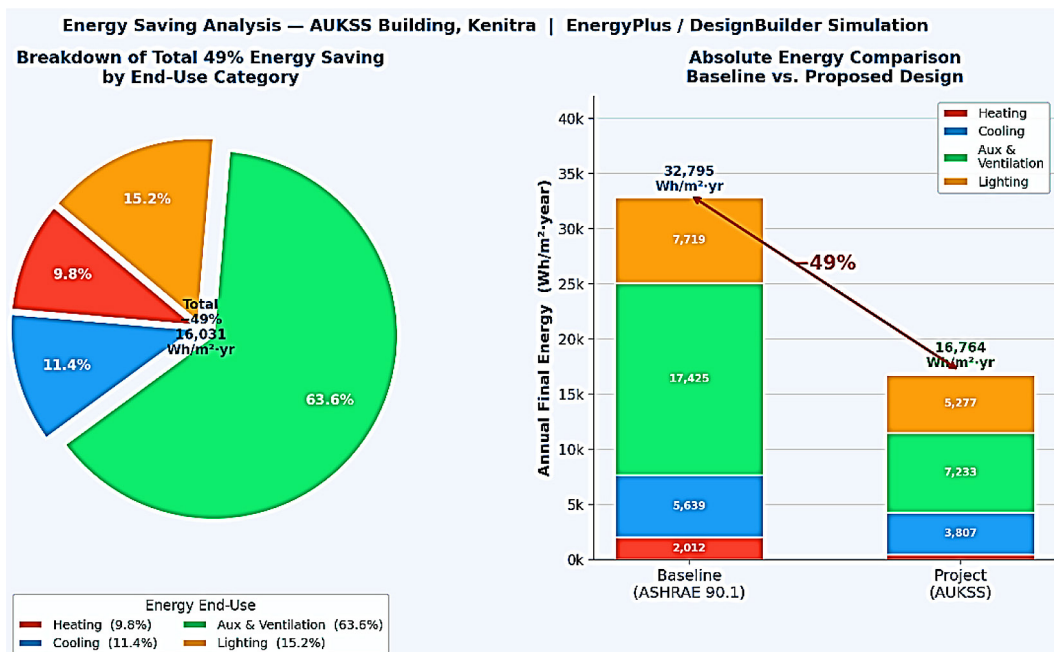


Figure 12. Breakdown of the total 49% energy saving (16,031 Wh/m²-year) by end-use category

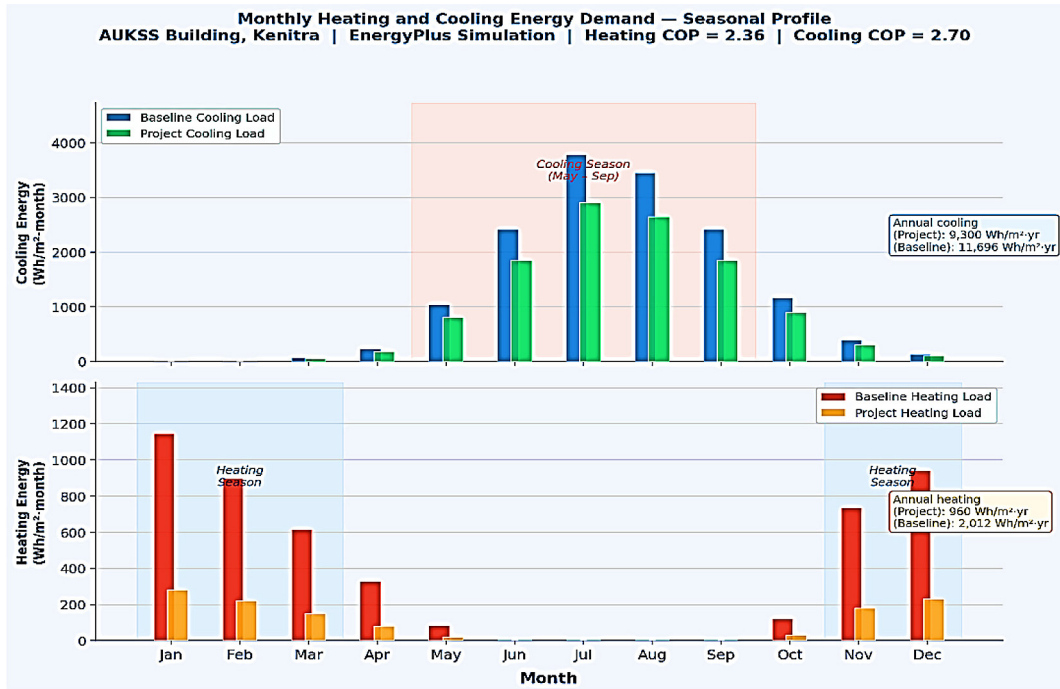


Figure 13. Monthly heating and cooling energy demand

heating sub-seasons. The project bars are consistently lower than the baseline in every month across both panels, confirming that the combined effect of envelope insulation, VRF efficiency, and

natural ventilation delivers year-round load reductions rather than seasonal improvements only. Annual totals shown in the annotation boxes: cooling baseline 11,696 vs project 9,300 Wh/m²-yr;

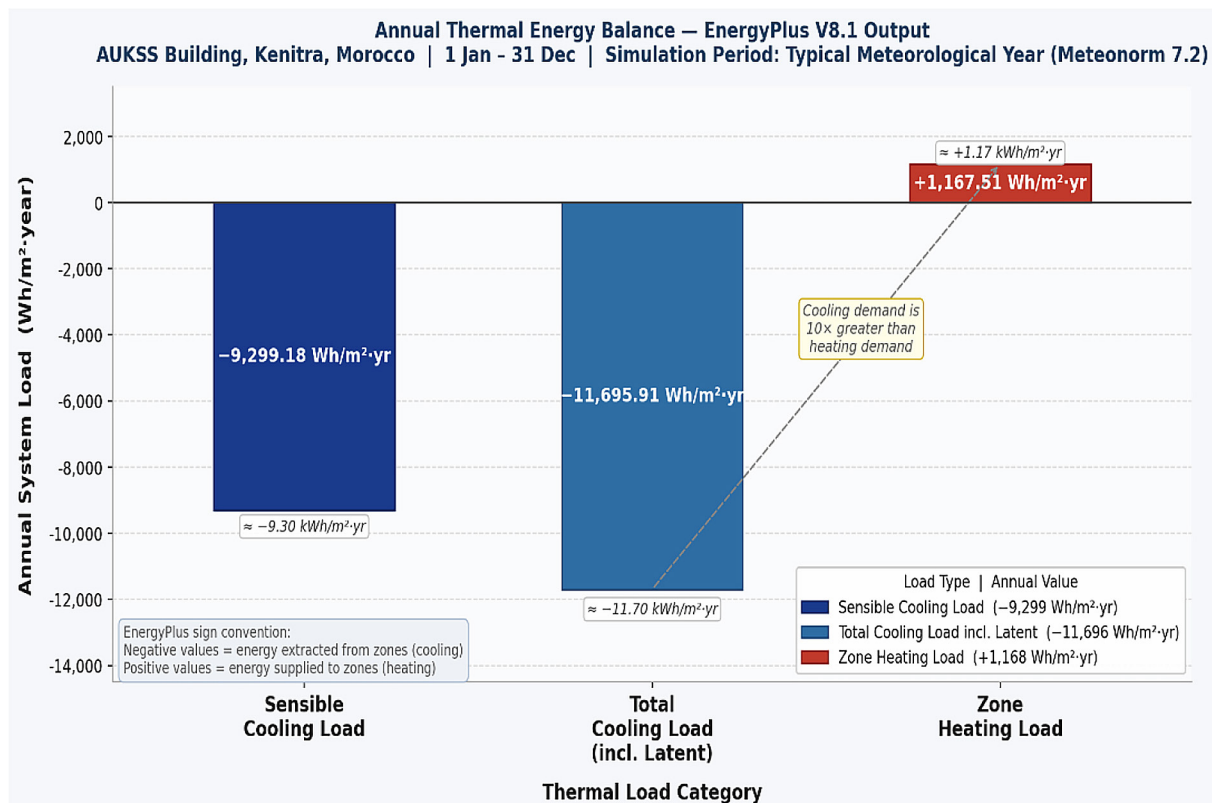


Figure 14. Annual thermal energy balance of the AUKSS building

heating baseline 2,012 vs project 960 Wh/m²·yr. Finally, Figure 14 presents the direct EnergyPlus thermal energy balance output for the proposed building. The horizontal bar chart uses the EnergyPlus sign convention: cooling loads are plotted as negative values (downward bars, blue), and heating loads as positive values (upward bars, red). The dark blue bar represents the sensible cooling load (−9.299 Wh/m²), the medium blue bar the total cooling load including latent heat (−11,696 Wh/m²), and the red bar the zone heating requirement (+1.168 Wh/m²). The large difference in magnitude between the cooling and heating bars visually confirms that the AUKSS building operates as strongly cooling-dominated throughout the year, a direct consequence of the humid Mediterranean climate of Kenitra.

Summer thermal comfort assessment

Summer thermal comfort was evaluated for four representative spaces covering all occupied floor levels: the IT room (Salle Informatique, R+1), workroom 1 (Salle de Travail 1, R+1), workroom 2 (Salle de Travail 2, R+2), and the multipurpose hall (Salle Polyvalente, RDC). These spaces were selected by Bureau Veritas as the critical zones for the HQE comfort assessment, representing high internal heat gain (IT equipment), standard office occupancy, upper-floor exposure, and large-volume ground-floor use respectively. The simulation period covers the full summer season from 1 April to 30 September, evaluated at hourly time-steps against the HQE operative temperature comfort threshold of 28 °C (HQE sub-target 8.3.1). All four spaces use assisted natural ventilation with mechanical extraction, with supply rates of 3 ACH and extraction rates of 12 ACH (IT room) or 6 ACH (all others), as prescribed by RTCM Zone 1 requirements.

The hourly operative temperature profiles for all four spaces are presented in Figure 15. In each panel, the blue curve shows the outdoor dry-bulb temperature fluctuating diurnally between approximately 15 °C and 42 °C across the season, the coloured curve shows the zone operative temperature, the dashed black horizontal line marks the 28 °C HQE threshold, the red shading highlights all hours where the operative temperature exceeds 28 °C, and the green bars on the right axis show the instantaneous ventilation rate in ACH. Three key patterns are visible across all panels. First, the zone operative temperature

tracks significantly below the outdoor peak in all spaces, confirming that the combination of envelope insulation, solar shading, and assisted natural ventilation successfully decouples interior comfort from exterior heat stress. Second, exceedance events are brief and concentrated in late July to mid-August, corresponding to the meteorological peak of the Kenitra summer. Third, the IT Room panel (a) shows the largest number of exceedance hours due to its high continuous internal heat gain from server equipment, while workroom 2 on the upper floor panel (c) paradoxically achieves the lowest exceedance owing to its east-facing orientation, reduced solar exposure, and proximity to the open terrace.

The quantitative compliance results for all four spaces are summarised in Table 5. The IT Room achieves 2.00% exceedance, which corresponds to 4 HQE points, the minimum passing score under sub-target 8.3.1 (threshold: ≤ 2%). The three remaining spaces, workroom 1 (0.13%), workroom 2 (0.03%), and the multipurpose hall (0.60%), all achieve exceedances below 1%, earning the maximum score of 6 HQE points each. All four spaces, therefore, comply with sub-target 8.3.1, confirming that the proposed design strategy maintains thermally acceptable conditions throughout the occupied summer period despite the challenging humid Mediterranean climate of Kenitra.

Rooftop photovoltaic system

The proposed PV installation is positioned on the accessible flat roof of the AUKSS building (floor R+3), occupying 116 m² on the south-facing portion of the terrace as illustrated in Figure 16 (roof plan). The array consists of 60 Jinko-Solar JKM 360M-72V monocrystalline modules (360 Wc each) arranged in 4 parallel strings of 15 modules in series, connected to 4 × Fronius Symo 4.5-3-S three-phase inverters (4.5 kWac each, 18.0 kWac total). The system is fixed at a 32° tilt angle, south-facing (azimuth 0°), selected to maximise annual yield for the Kenitra latitude (34.26°N). The PVsyst system configuration, including all module and inverter parameters used in the simulation, is presented in Figure 17.

The monthly PV energy production and its relationship to building electricity consumption are shown in Figure 18. The PV bars (orange) follow the seasonal irradiation curve of Kenitra, rising from 1.783 kWh in January to a peak of 4.672

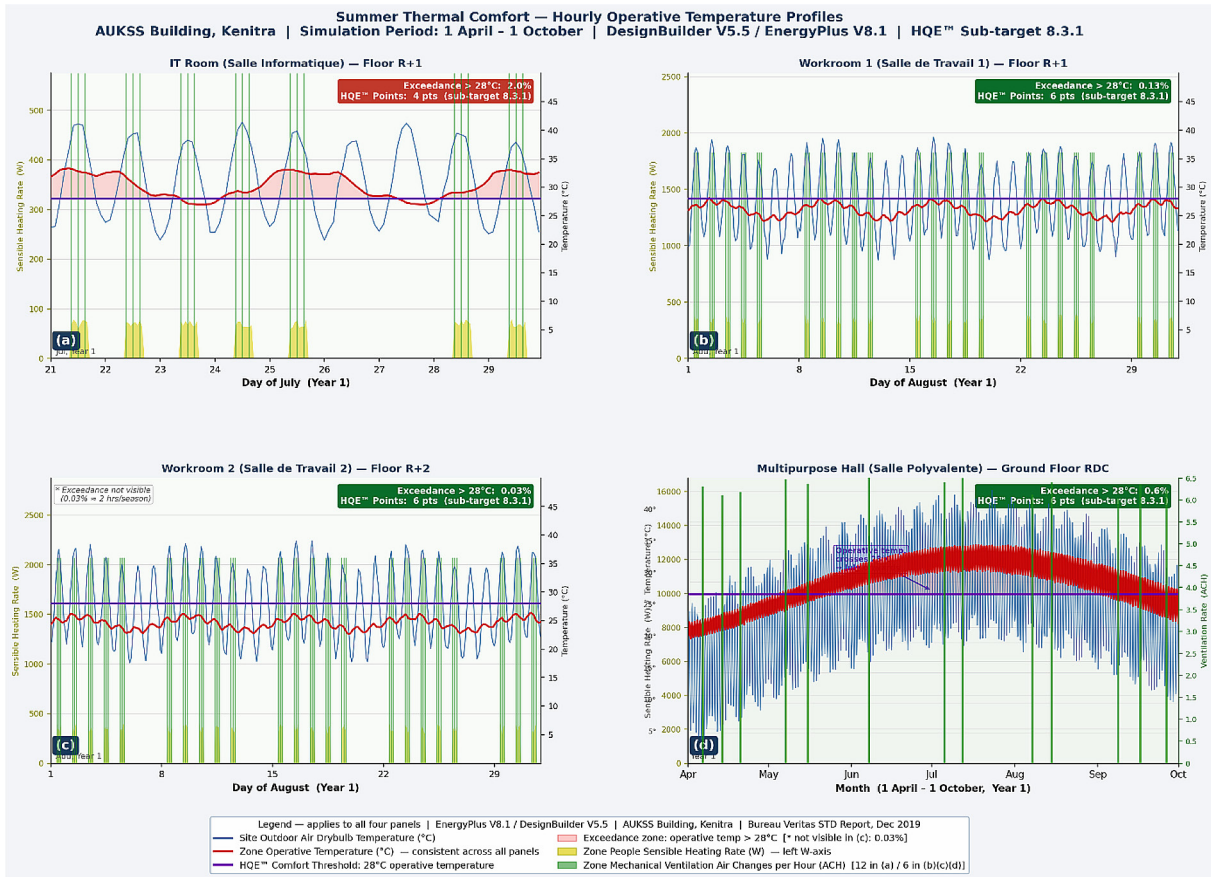


Figure 15. Hourly operative temperature profiles during the summer simulation period (1 April to 30 September) for the four studied spaces: (a) IT room, floor R+1; (b) workroom 1, floor R+1; (c) workroom 2, floor R+2; (d) multipurpose hall, ground floor RDC

Table 5. Summer thermal comfort assessment – HQE sub-target 8.3.1 compliance summary

Space	Floor	Function	Ventilation strategy	Supply / Extraction (ACH)	Operative temp. Exceedance >28 °C (%)	HQE™ points (sub-target 8.3.1)
IT Room (Salle Informatique)	R+1	Computer lab / Server room	Mechanical extraction + natural supply	3 / 12	2.00%	4 pts
Workroom 1 (Salle de Travail 1)	R+1	Open-plan office	Mechanical extraction + natural supply	3 / 6	0.13%	6 pts
Workroom 2 (Salle de Travail 2)	R+2	Open-plan office	Mechanical extraction + natural supply	3 / 6	0.03%	6 pts
Multipurpose Hall (Salle Polyvalente)	RDC	Meeting / multipurpose	Mechanical extraction + natural supply	3 / 6	0.60%	6 pts

kWh in July (corresponding to the maximum daily irradiation of 7.78 kWh/m²·day on the tilted plane), before declining to 1.657 kWh in December. The building consumption bars (blue) remain relatively stable year-round (between ~5.100 and ~8.400 kWh/month), with a slight peak in summer driven by cooling loads. The monthly coverage rate (red line, right axis) ranges from 22.2% in December to 57.5% in May, with the highest

coverage occurring in spring rather than peak summer because May combines high irradiation with moderate (non-peak) cooling demand. The annual average coverage of ~30% is consistent with the design target of covering 30% of building consumption by photovoltaics.

The complete system performance and economic assessment is consolidated in Table X. Over its 20-year guaranteed lifetime, the system

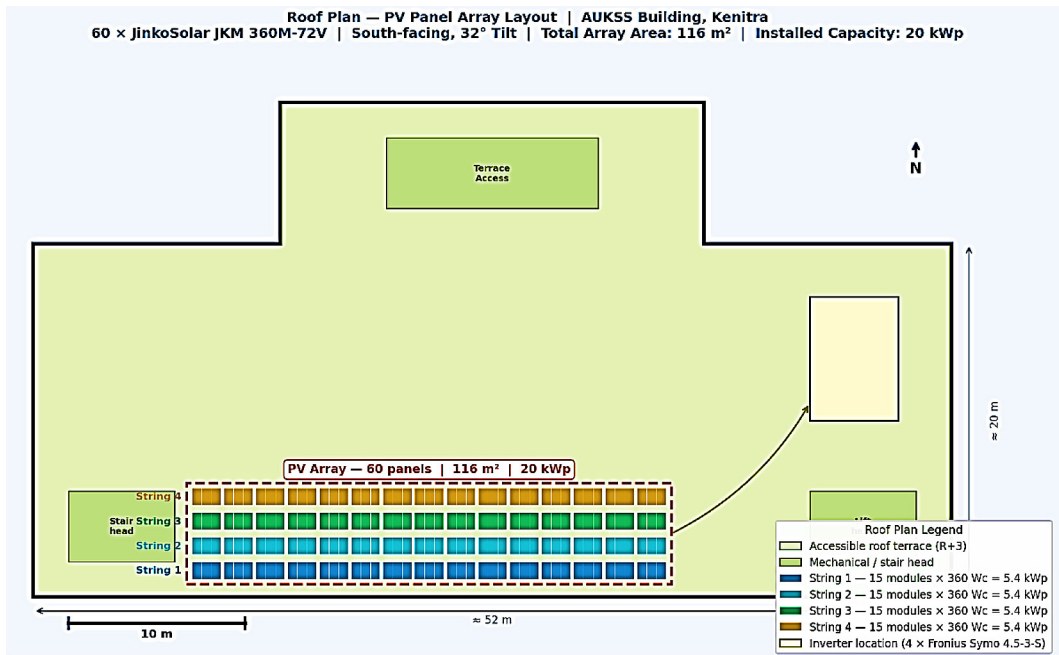


Figure 16. Schematic roof plan of the AUKSS building (R+3 terrace) showing the proposed PV array layout

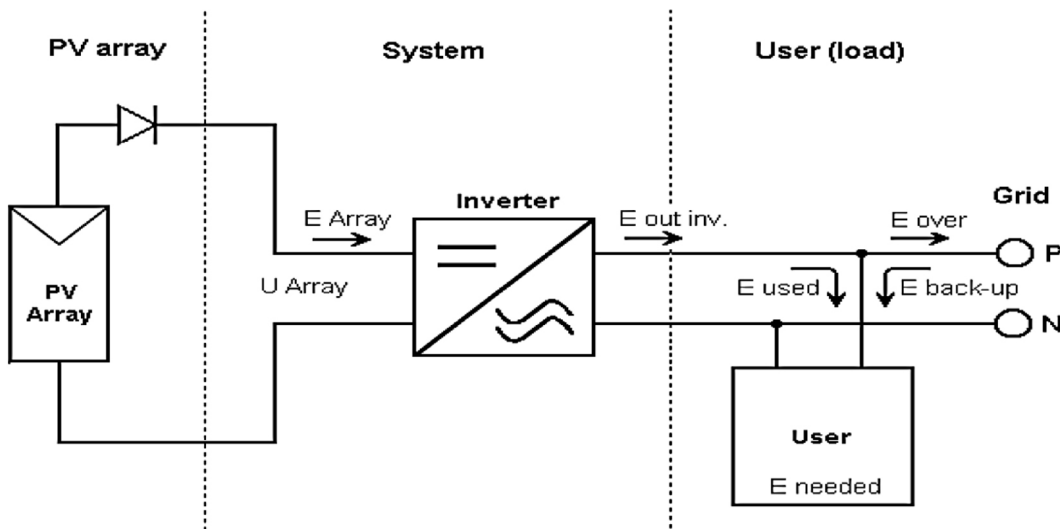


Figure 17. PV system configuration output for the AUKSS building PV installation

generates 758,800 kWh of electricity, avoids approximately 304,000 kg of CO₂ emissions (based on the Morocco national grid emission factor of 0.401 kg CO₂/kWh), and delivers gross financial savings of 1,138,200 MAD HT at the current electricity tariff of 1.50 MAD HT/kWh. The simple payback period is 7.01 years, well within the 20-year panel warranty period, yielding a net 20-year revenue of 898,894 MAD HT – equivalent to a return of +225% on the initial investment of 399,083 MAD HT. The system contributes to HQE sub-target 4.1 (renewable energy integration) and supports the building’s overall primary

energy reduction from 73.87 to 42.56 kWh/m²·year (Figure 19).

DISCUSSION

The results of the dynamic thermal simulation and the integrated environmental performance assessment of the AUKSS headquarters building reveal a coherent and mutually reinforcing set of outcomes across four performance domains: thermal envelope compliance, energy efficiency, summer thermal comfort, and on-site renewable energy generation.

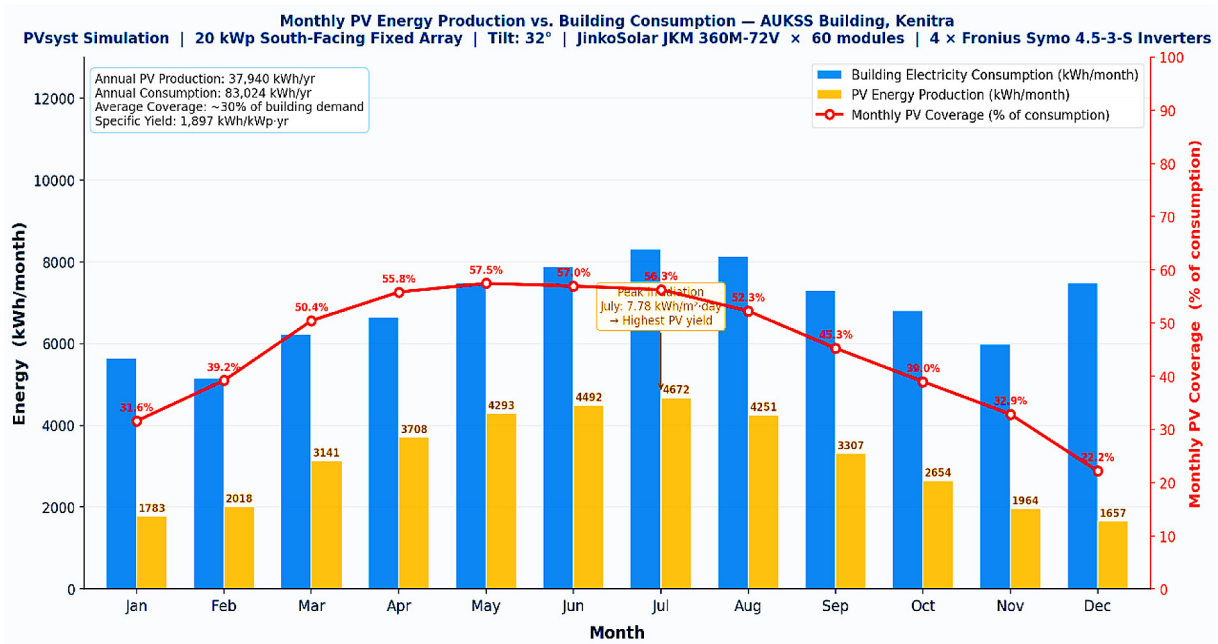


Figure 18. Monthly PV energy production (orange bars, left axis) vs. building electricity consumption

PV System Performance & Economic Summary — AUKSS Building, Kenitra, Morocco		
System Design & Configuration	Energy Performance Results	Economic Assessment (20-Year)
Installed Capacity: 20 kWp	Annual PV Production: 37,940 kWh/year	Total Investment: 399,083 MAD HT
Number of Modules: 60 modules	Specific Yield: 1,897 kWh/kWp-year	Investment per m ² : 3,440 MAD HT/m²
Module Type: JinkoSolar JKM 360M-72V	20-Year Total Production: 758,800 kWh	Electricity Tariff: 1.50 MAD HT/kWh
Module Technology: Monocrystalline Si	Building Annual Consumption: 83,024 kWh/year	Annual Financial Savings: 56,910 MAD/year
Module Power (STC): 360 Wc / module	% Consumption Covered: ~30% of total demand	Simple Payback Period: 7.01 years
Module Efficiency (STC): 18.57%	Peak Month: July — 4,560 kWh	20-Year Gross Savings: 1,138,200 MAD HT
Modules per String: 15 (series)	Lowest Month: December — 1,450 kWh	20-Year Net Revenue: 898,894 MAD HT
Number of Strings: 4 (parallel)	Mean Daily Irradiation: 5.37 kWh/m²-day (tilted)	Return on Investment (20yr): +225% of initial investment
Number of Inverters: 4 x Fronius Symo 4.5-3-5	Annual Irradiation (tilted): 1,960 kWh/m²-year	CO ₂ Cost Savings (est.): ≈ 15,200 kg/yr x tariff
Inverter Power (each): 4.50 kWac	System Performance Ratio: ≈ 0.83 (PR)	HQE Sub-target: 4.1 — Renewable Energy
Total AC Power: 18.0 kWac	Losses — Thermal: -0.39%/°C (Pmax)	Grid Export: Surplus fed to grid (réseau)
Roof Area Used: 116 m ²	Losses — Cable/Wiring: 1.5% (STC)	Panel Warranty: 20 years product warranty
Panel Orientation: South-facing (Azimuth 0°)	Losses — Module Quality: -0.8%	Performance Guarantee: 90% output @ 10 yr
Tilt Angle: 32° fixed	CO ₂ Avoided (annual): ≈ 15,200 kg CO₂/year	Performance Guarantee: 80% output @ 20 yr
Connection Type: Grid-connected	CO ₂ Avoided (20 years): ≈ 304,000 kg CO₂	Manufacturer: JinkoSolar / Fronius Int.

Figure 19. PV system performance and economic summary for the AUKSS building rooftop installation

Thermal envelope performance

The envelope achieves thermal transmittance values substantially below the RTCM Zone 1 prescriptive limits across all regulated components. The external wall ($U = 0.409 \text{ W/m}^2\cdot\text{K}$) performs 66% better than the regulatory ceiling of $1.20 \text{ W/m}^2\cdot\text{K}$, while the roof assembly ($U = 0.50 \text{ W/m}^2\cdot\text{K}$)

operates 9% below the most stringent applicable limit of $0.55 \text{ W/m}^2\cdot\text{K}$, the tightest threshold in the 36–45% TGBV category to which the building belongs ($\text{TGBV} = 43.35\%$). The external double-glazed units ($U = 2.50 \text{ W/m}^2\cdot\text{K}$, $\text{FS} = 0.70$) remain 24% below the glazing limit of $3.30 \text{ W/m}^2\cdot\text{K}$. These margins are not incidental: the insulated double-brick wall construction with 50 mm

rockwool and the 40 mm expanded cork roof insulation respond directly to the thermophysical requirements of the humid Mediterranean climate of Kenitra, where both winter thermal resistance and summer decrement factor are critical. The relatively smaller margin for the roof (9%) identifies this component as the most constrained element of the design and suggests that increasing cork insulation from 40 mm to 60 mm would provide additional summer resilience at marginal cost, a refinement worth incorporating in future iterations.

Daylighting performance

The radiance-based daylighting simulation (CIE Uniform Overcast Sky, DesignBuilder V5.5/Radiance, 0.5×0.5 m mesh) shows a progressive improvement in daylight factor compliance with floor level: from 31–72% of floor area achieving $DF \geq 2.5\%$ on the ground floor (RDC) to 72–94% on the top floor (R+3), depending on threshold. The pattern reflects the combined effect of the central atrium, which channels diffuse light into the building core on lower floors, and the increasing sky exposure on upper floors. The gradient between ground and top floors is particularly pronounced for the $DF \geq 2.5\%$ threshold (31% vs 72%), confirming that the atrium strategy improves daylighting substantially but cannot fully compensate for the obstruction by surrounding built volumes at ground level. This finding is consistent with studies on deep-plan administrative buildings with central voids in warm climates, where atrium geometry must balance daylighting penetration against overheating risk.

Energy performance

The overall energy saving of 49% relative to the ASHRAE 90.1 System 6 baseline ($32,795 \rightarrow 16,764$ Wh/m²·year) exceeds the minimum 10% threshold required for HQE™ sub-target 4.2.1, qualifying the building for the maximum 7 points under this sub-target. In primary energy terms, the proposed design achieves 42.56 kWh/m²·year against a baseline of 73.87 kWh/m²·year, corresponding to a primary energy reduction of 42% – well below the 49 kWh/m²·year BECTh reference limit for Zone Z2 tertiary administrative buildings. The breakdown of savings by end-use reveals a clear hierarchy: auxiliary systems and ventilation contribute 63.6% of total savings (10,192 Wh/m²·yr, – 58%), followed by lighting

at 15.2% (2,442 Wh/m²·yr, – 32%), cooling at 11.4% (1,832 Wh/m²·yr, – 32%), and heating at 9.8% (1,564 Wh/m²·yr, – 78%). The dominance of the ventilation and auxiliary category confirms that HVAC system selection is the single most impactful design decision for this building typology. The shift from a centralised packaged VAV baseline (System 6) to a zone-level three-pipe VRF system for north-facing spaces combined with assisted natural ventilation for south-facing spaces produces a step-change reduction that envelope improvements alone could not achieve. The –78% heating saving reinforces the compatibility of this mild-winter site with high-performance passive-first strategies: the insulated envelope and solar gains through the south-facing glazing ($FS = 0.70$) are sufficient to suppress heating demand to near-negligible levels (447 vs 2,012 Wh/m²·yr). The CO₂ reduction of 42% (1,594 vs 2.75 kg eq CO₂/m²·yr), corresponding to 3 HQE points under sub-target 4.3.1, quantifies the direct climate benefit of these performance gains.

Summer thermal comfort

The operative temperature analysis across four representative spaces confirms compliance with HQE™ sub-target 8.3.1 in all cases. Three spaces – workroom 1 (0.13%), workroom 2 (0.03%), and the multipurpose hall (0.60%) — achieve exceedances well below 1% of annual occupied hours, earning the maximum 6 HQE points. The IT Room achieves the threshold score of 4 points (2.00% exceedance), which represents the tightest margin in the assessment and reflects the challenge of managing continuous high-density equipment loads (12 ACH extraction) in a sealed server-type environment during Kenitra’s peak summer weeks (late July to mid-August). It is significant that this space achieves compliance despite its thermal load intensity, confirming that the 12 ACH mechanical extraction combined with 3 ACH natural supply effectively prevents operative temperature accumulation. The contrast between the IT room (2.0%) and workroom 2 (0.03%) is instructive: although both are on floor R+1/R+2, the absence of continuous equipment loads and the east-facing orientation of workroom 2 with access to the open terrace reduce its thermal stress dramatically. This spatial differentiation in comfort outcomes would not have been visible from a building-level analysis alone and

underscores the value of space-resolved, dynamic simulation for HQE certification.

Photovoltaic system and economic viability

The 20 kWp rooftop PV installation ($60 \times$ JinkoSolar JKM 360M-72V, $4 \times$ Fronius Symo 4.5-3-S, 32° tilt, south-facing) produces an estimated 37,940 kWh/year, covering approximately 30% of the building's annual electricity demand of 83,024 kWh. The specific yield of 1,897 kWh/kWp-year is consistent with PVsyst modelling benchmarks for Kenitra's solar resource (annual irradiation on tilted plane: 1.960 kWh/m²-year, mean daily global irradiation on 32° tilted plane: 5.37 kWh/m²-day). Monthly coverage ranges from 22% in December to 58% in May, with the spring maximum reflecting the favourable combination of high irradiation and moderate cooling demand. The simple payback period of 7.01 years, within a 20-year guaranteed panel lifetime, results in 20-year gross savings of 1,138,200 MAD HT and a net revenue of 898,894 MAD HT, a return of +225% on the initial investment of 399,083 MAD HT. These metrics confirm the financial robustness of the PV component even at the conservative 30% coverage target. The choice of 30% rather than full self-sufficiency reflects a deliberate optimisation: increasing installed capacity beyond 20 kWp would generate overproduction during high-irradiation months (May–August) that cannot be self-consumed and would require grid export at unfavourable feed-in conditions, while the 20 kWp scale keeps the array within the available roof area (116 m² of 116 m² total accessible surface) without encroaching on maintenance zones.

Study limitations

Several sources of uncertainty should be acknowledged. The EnergyPlus simulation was conducted with a representative meteorological year (Meteonorm 7.2, 1986–2005), which may not capture the increasing frequency of extreme heat events observed in northwestern Morocco in recent years. Airtightness was assumed at 1.7 m³/h/m² at 4 Pa, consistent with RTCM requirements, but actual construction quality and system commissioning will determine whether this value is achieved in practice. The monthly PV production profile was derived by distributing the annual PVsyst yield proportionally to the monthly

tilted-plane irradiation, as individual monthly outputs were not separately reported in the STD; this does not affect the annual totals but introduces uncertainty in seasonal coverage estimates. Finally, occupant behaviour, particularly window operation in naturally ventilated south-facing spaces, introduces an irreducible variable that simulated schedules cannot fully capture.

CONCLUSIONS

This study presents the first integrated environmental performance assessment of a Moroccan public administrative building under the HQE international framework, using dynamic thermal simulation (Design Builder V5.5.2 / EnergyPlus V8.1) as the primary evaluation method. The AUKSS building, located in Kenitra (RTCM Zone 1, humid Mediterranean climate, 34.26°N), demonstrates that the simultaneous objectives of regulatory compliance, occupant comfort, operational energy efficiency, and on-site renewable energy integration can be achieved within the constraints of a standard public procurement project.

The key quantitative findings are: (i) full RTCM Zone 1 prescriptive envelope compliance, with the external wall 66% below limit ($U = 0.409 \text{ W/m}^2\cdot\text{K}$), roof 9% below limit ($U = 0.50 \text{ W/m}^2\cdot\text{K}$), and glazing 24% below limit ($U = 2.50 \text{ W/m}^2\cdot\text{K}$); (ii) a 49% total energy saving relative to the ASHRAE 90.1 System 6 baseline, driven primarily by the VRF system and assisted natural ventilation strategy (63.6% of savings from HVAC), producing a final primary energy intensity of 42.56 kWh/m²-year, 13% below the BECTh reference; (iii) full HQE sub-target 8.3.1 compliance across all four studied spaces, with operative temperature exceedances ranging from 0.03% to 2.00% of annual occupied hours, and a minimum score of 4 HQE points even in the thermally demanding IT room; (iv) a 42% CO₂ intensity reduction (1.594 vs 2.75 kg eq CO₂/m²-yr) earned under HQETM sub-target 4.3.1; and (v) a 20 kWp rooftop PV system covering 30% of annual electricity demand, with a simple payback of 7.01 years, 20-year gross savings of 1,138,200 MAD HT, and an estimated 304,000 kg CO₂ avoided over the panel lifetime.

These results demonstrate that the greatest leverage for energy performance in humid Mediterranean administrative buildings lies not in envelope optimisation alone but in the selection

of zone-level HVAC strategies that match system type to façade orientation and internal load profile. The north-facing VRF zone strategy and south-facing assisted natural ventilation approach together account for more than half the total energy savings and should be considered as a replicable design pattern for similar public buildings across RTCM Zone 1.

The AUKSS building therefore constitutes a validated reference case for sustainable institutional architecture in Morocco, combining regulatory compliance (RTCM/RGCPÉB), international certification (HQE international), and long-term economic viability into a coherent design framework. Future work should address three identified areas of improvement: increasing roof insulation thickness to widen the thermal safety margin beyond 9%; extending the comfort and daylighting analysis to the basement level and to non-standard occupancy scenarios such as weekend events in the multipurpose hall; and conducting post-occupancy monitoring to validate simulation predictions against measured energy consumption data, thereby closing the performance gap between design intent and operational reality that remains a persistent challenge across the building energy performance field.

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