Net / Near Zero Emission Building (NZEB) Design

Principles, Strategies, and Technologies for Sustainable Architecture

By Manus Heunis
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Introduction to NZEBs

Net / Near Zero Energy Buildings (NZEBs) produce as much energy as they consume annually, primarily from on-site renewables.

Core Approach

Minimize demand first (passive design + efficiency)
→ Meet remaining needs with renewables

50-80%

Energy reduction achievable through passive strategies alone

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Achieving NZEB Through Integrated Design

NZEB design is achieved by harnessing the best of both passive and active technologies — reducing demand first, then meeting the balance with efficient systems and renewables.

Passive Strategies

Orientation, insulation, thermal mass, shading, and natural ventilation to minimize energy demand

Active Technologies

Solar PV, heat pumps, efficient HVAC, and smart energy management to supply remaining needs

Reduce Demand First

Passive design can cut energy demand by 50–80%, making active systems smaller and more cost-effective

Generate and Optimize

Active systems and on-site renewables cover the remaining energy gap to reach net zero

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Why NZEBs Matter

Natural elements — sun, wind, earth, water, vegetation — are foundational for reducing energy use and creating resilient buildings.

Lower Emissions

Dramatically reduced carbon footprint through passive-first design and on-site renewables

Cost Savings

Significant long-term operational savings with minimal energy bills over building lifetime

Improved Comfort

Superior thermal comfort, air quality, and natural daylighting for occupants

Climate Resilience

Reduced dependency on external energy grids and adaptation to climate variability

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PART 1 – PASSIVE DESIGN STRATEGIES

The Role of Natural Elements in NZEB Design

Harnessing Climate, Sun, and Passive Strategies for Net / Near Zero Energy Architecture

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Chapters

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Chapter 1

Milankovitch Cycles

Long-Term Climate Drivers

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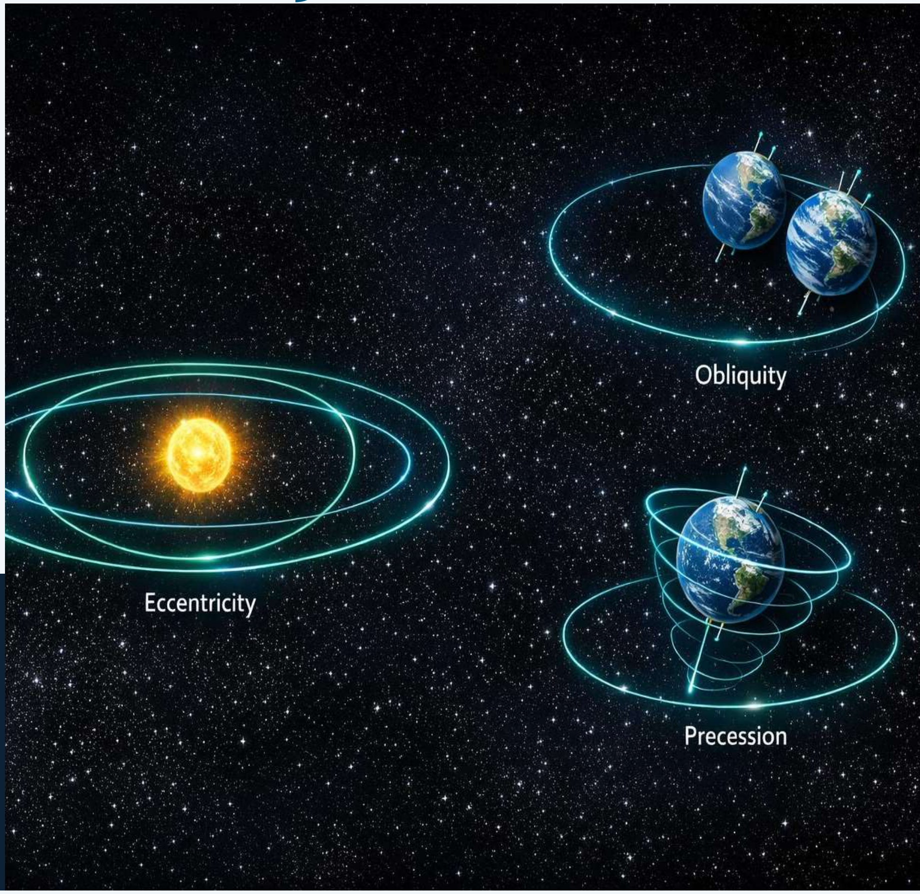
Introduction to Milankovitch Cycles

Long-term periodic changes in Earth's orbit, tilt, and axis orientation that drive major climate shifts over tens of thousands of years.

These cycles operate on timescales of **10,000 to 100,000+ years** and are the primary drivers of glacial-interglacial cycles throughout Earth's history.

These orbital variations alter the intensity and distribution of sunlight reaching Earth — forming the foundation for understanding long-term climate context in building design.



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The Three Main Components

1

Eccentricity *~100,000-year cycle*

Shape of Earth's orbit varies from nearly circular to more elliptical. Affects Earth-Sun distance and seasonal contrast in different hemispheres.

2

Obliquity (Tilt) *~41,000-year cycle*

Axial tilt varies between 22.1° and 24.5°. Greater tilt produces stronger seasons and significantly influences high-latitude insolation patterns.

3

Precession *~26,000-year cycle*

Wobble of Earth's axis changes the timing of seasons relative to orbital position — determining which hemisphere receives more intense summer sunlight.

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Impact on Climate and Insolation

Alter intensity and distribution of sunlight reaching Earth's surface across latitudes and seasons

Primary drivers of ice ages — small insolation changes amplified by feedbacks (ice albedo, CO_2, ocean currents)

Understanding long-term climate variability informs resilient NZEB design in a changing world

Adapting to shifting temperature patterns over decades and centuries is essential for future-proof NZEB design.

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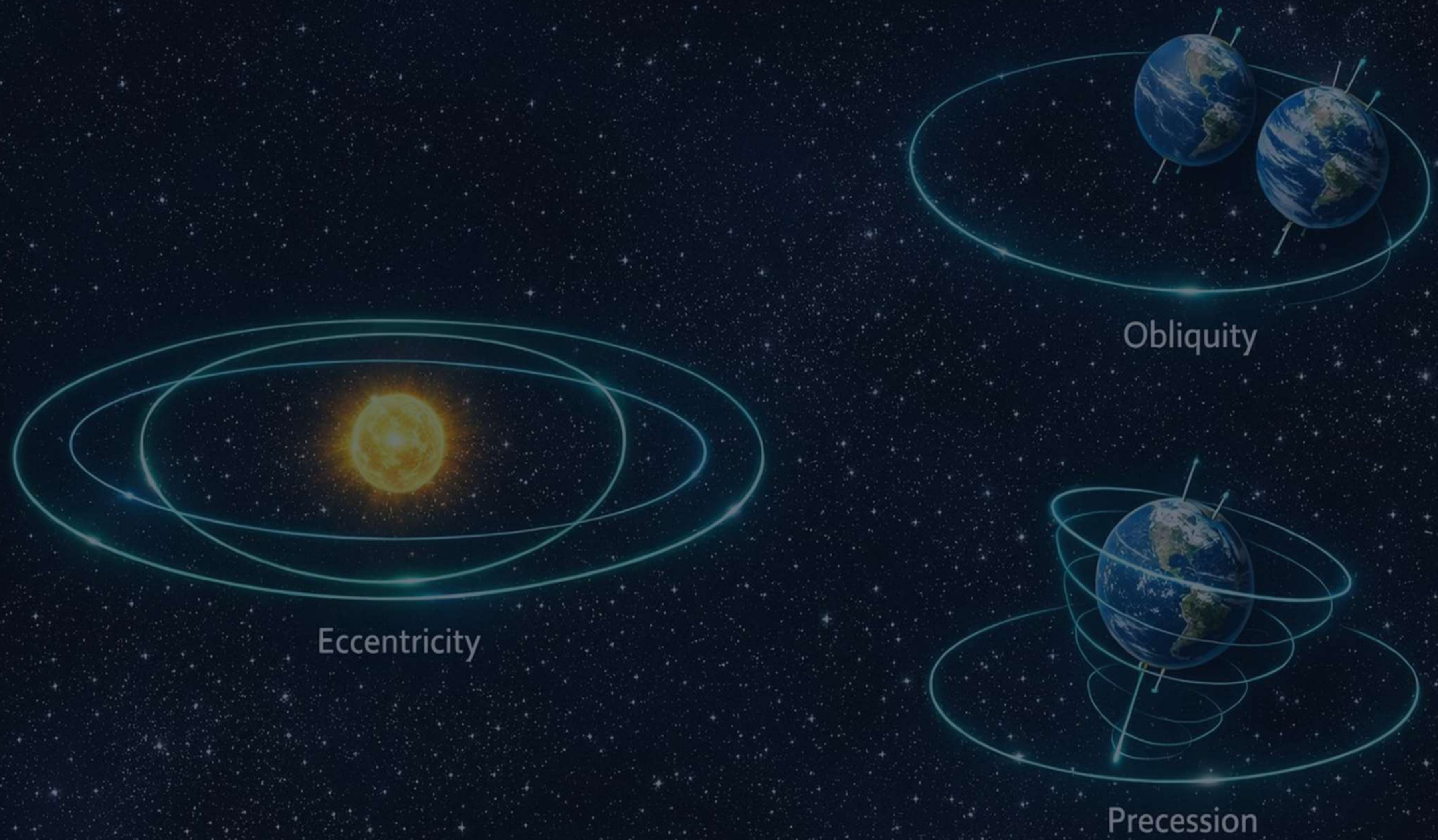
Milankovitch Cycles — Visual Overview



Standard orbital diagrams illustrating eccentricity, obliquity, and precession cycles mapped against historical temperature and insolation records.

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Chapter 2

Insolation

Latitude, Seasons, and Building Placement

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What Is Insolation?

Incoming solar radiation — the energy per unit area reaching a surface. This is the key variable for passive solar heating, daylighting, and photovoltaic performance.

Insolation Depends On:

Latitude
Distance from equator

Season
Earth's axial tilt

Time of Day
Solar elevation angle

Atmosphere
Clouds and pollution

Surface Orientation
Tilt and azimuth

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Latitude Effects on Insolation

Equatorial (0-23.5°N&S)

High year-round insolation with minimal seasonal variation. Cooling-dominant design focus.

Mid-Latitudes (30-60° N&S)

Pronounced seasons. Optimal for passive solar with south-facing orientations (NH) and north-facing (SH). Greatest design opportunity.

High Latitudes (60°+ N&S)

Low winter sun angles create challenges for solar gain but opportunities for extended summer daylight. Applicable to both Northern and Southern Hemispheres.

Building placement: Site analysis is critical for orientation and shading optimization

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Seasonal Sun Positioning

Winter (Northern Hemisphere)

- Low sun angle (~26° at noon, 40°N)
- Deeper penetration into interiors
- Maximizes passive solar heating
- South-facing glazing captures heat

Summer (Northern Hemisphere)

- High sun angle (~73° at noon, 40°N)
- Easier to shade with overhangs
- Louvers prevent overheating
- Critical for cooling load reduction

Sun path diagrams are essential in design — tools like Climate Consultant and Ladybug enable precise analysis of solar geometry for any location.

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Design Implications for NZEB

Optimize glazing, orientation, and shading based on local insolation data.

Key Design Tools

Solar Heat Gain Coefficients (SHGC)
Calculate optimal glazing properties for each facade orientation

Climate-Specific Modeling
Use local weather data to simulate annual energy performance

Sun Path Analysis
Map solar angles throughout the year for shading design

Thermal Simulation
Model heat flows through the building envelope under varying conditions

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Chapter 3

Passive Design Technologies

Leveraging Natural Elements for Energy Reduction

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Overview of Passive Design in NZEB

Leverage natural elements to reduce heating, cooling, and lighting loads dramatically — often by 50–80% compared to conventional buildings.

Sun	Wind	Earth	Water	Vegetation
Solar heating and daylighting	Natural ventilation and cooling	Thermal mass and ground coupling	Evaporative and thermal cooling	Shading and microclimate

These natural forces, when harnessed through intelligent design, form the foundation of every successful NZEB.

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Building Orientation

Align long axis east-west to maximize the south facade (in the Northern Hemisphere). This single decision dramatically impacts energy performance.

Maximize South Exposure (NH)

Elongated south facade captures maximum winter solar gain for passive heating

Minimize East/West Gain

Reduce difficult-to-shade low-angle morning and afternoon summer sun

Wind Synergies

Orientation can optimize natural ventilation pathways for cooling

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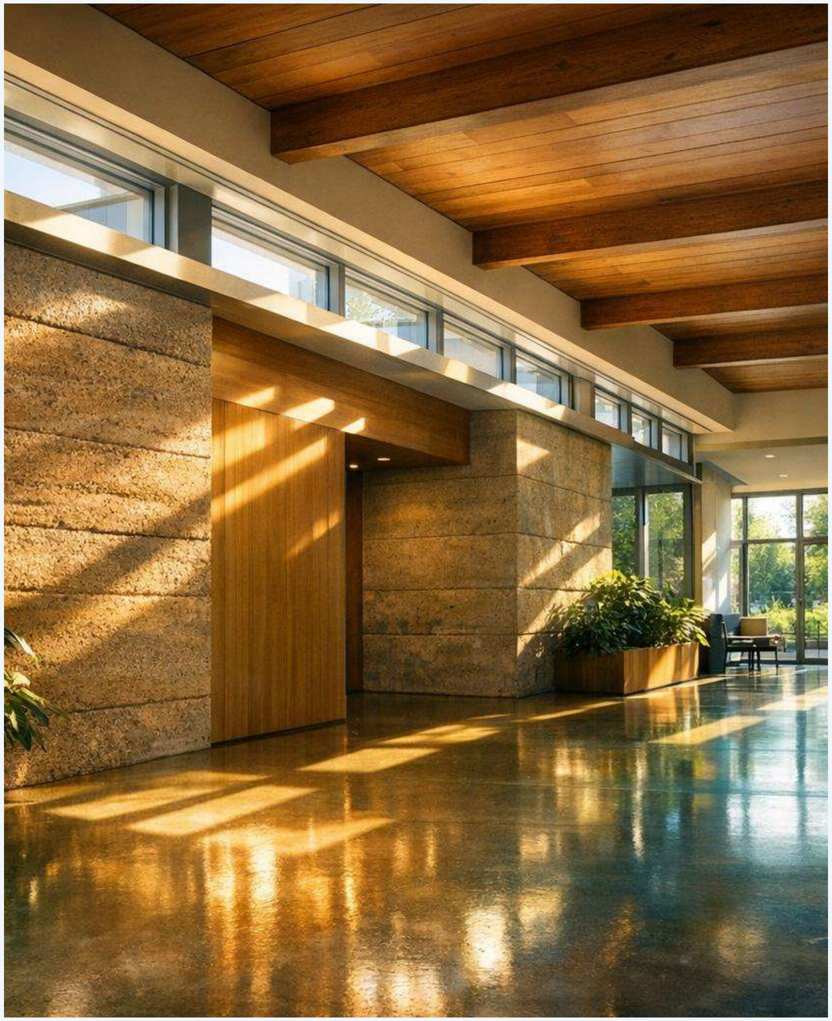
Thermal Mass

Materials like concrete, stone, and rammed earth absorb, store, and release heat slowly — stabilizing indoor temperatures throughout the day.

- Absorb daytime solar heat, release at night
- Pair with night flushing in suitable climates
- Reduce peak heating and cooling loads
- Concrete, stone, water, PCMs as storage media

Thermal mass can reduce daily temperature swings by 5–10°C



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Green Walls and Shading Systems

Green Walls and Roofs

- Evaporative cooling effect
- Added insulation layer
- Biodiversity and aesthetics
- Reduce urban heat island effect
- Increase the urban jungle effect
- Stormwater management

Shading Systems

- Overhangs and louvers
- External fins and blinds
- Deciduous trees for seasonal shade
- Block summer sun, allow winter
- Dynamic vs. fixed approaches

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1. Evaporative Cooling Effect

Green walls and roofs use plant transpiration and moisture evaporation to naturally cool surrounding air — reducing ambient temperatures by 3–5°C without mechanical energy input.

- Reduces surface temperatures on walls and roofs by up to 10°C
- Lowers indoor cooling loads by 25–40% in warm climates
- Improves outdoor thermal comfort in urban courtyards and plazas
- Applications: hospitals, schools, commercial facades, urban retrofits

Evaporative cooling from green walls can cut air conditioning demand by up to 40%

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2. Added Insulation Layer

Vegetated roofs and walls create an additional thermal buffer — trapping air within foliage and substrate layers to reduce heat transfer through the building envelope.

- Adds R-value of 2–4 to existing wall and roof assemblies
- Reduces winter heat loss and summer heat gain simultaneously
- Extends waterproofing membrane lifespan by 2–3 times
- Applications: flat-roof retrofits, warehouse conversions, residential extensions

Green roof insulation can reduce annual heating and cooling energy by 15–25%

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3. Biodiversity and Aesthetics

Living walls and green roofs restore ecological habitats in urban environments while transforming stark building surfaces into vibrant, visually striking features.

- Supports pollinators, birds, and beneficial insects in dense urban areas
- Increases property values by 10–20% through enhanced visual appeal
- Improves occupant well-being, reducing stress and boosting productivity
- Applications: hotel facades, office atriums, public libraries, residential towers

Biodiverse green facades can support over 100 plant species on a single building

4. Reduce Urban Heat Island Effect

Widespread green roofs and walls can lower city-wide ambient temperatures by replacing heat-absorbing surfaces with vegetation that reflects sunlight and releases moisture.

- Reduces local air temperature by 1–3°C in densely built-up areas
- Cuts peak energy demand across neighborhoods during heat waves
- Mitigates smog formation linked to elevated urban temperatures
- Applications: city-wide green roof mandates, transit corridors, industrial zones

Cities with 50%+ green roof coverage can reduce peak temperatures by up to 3°C

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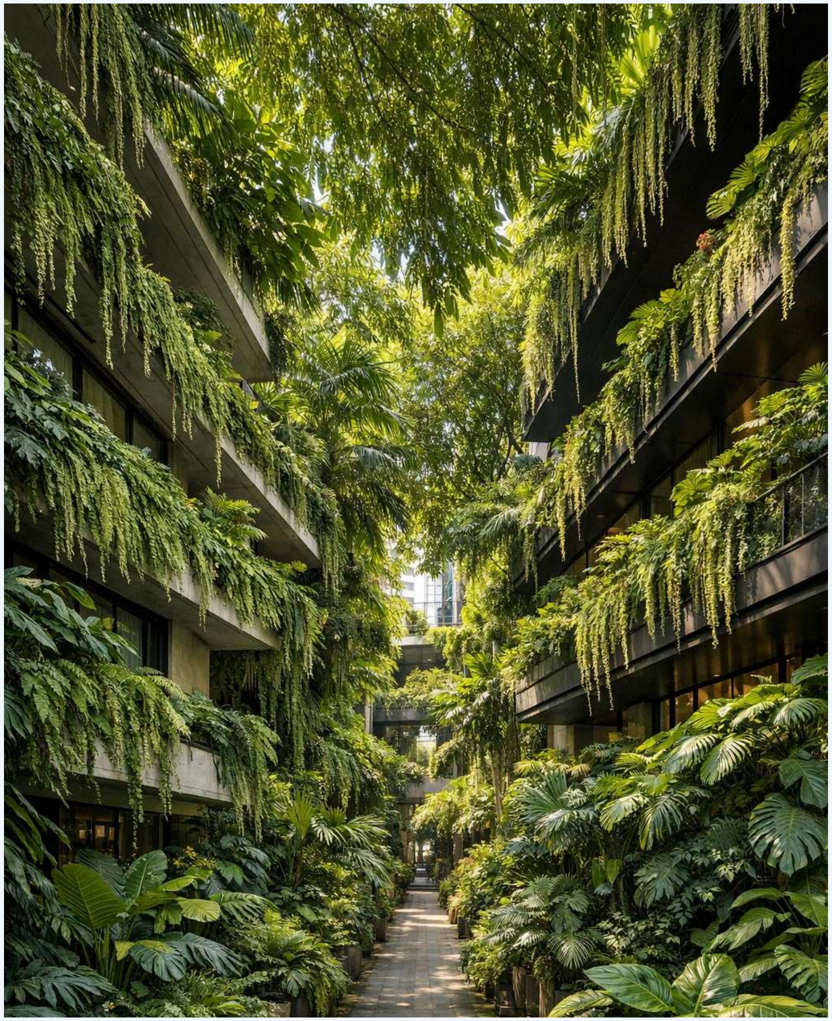
5. Increase the Urban Jungle Effect

Dense vertical greening transforms concrete corridors into lush urban canopies — creating interconnected green networks that improve air quality, shade, and livability.

- Filters airborne particulates and absorbs CO_2 at street level
- Creates shaded pedestrian corridors that encourage walking and cycling
- Connects fragmented urban habitats for wildlife movement
- Applications: streetscapes, highway sound barriers, parking structures, bridges

Urban green corridors can reduce street-level air pollution by 15–30%



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6. Stormwater Management

Green roofs capture, store, and slowly release rainwater — reducing peak runoff volumes and easing pressure on aging municipal drainage infrastructure.

- Retains 50–80% of annual rainfall on extensive green roofs
- Delays peak stormwater runoff by 30–60 minutes during heavy rain
- Reduces combined sewer overflow events in older urban systems
- Applications: commercial rooftops, municipal buildings, new housing developments

A single green roof can retain up to 75% of annual precipitation on site

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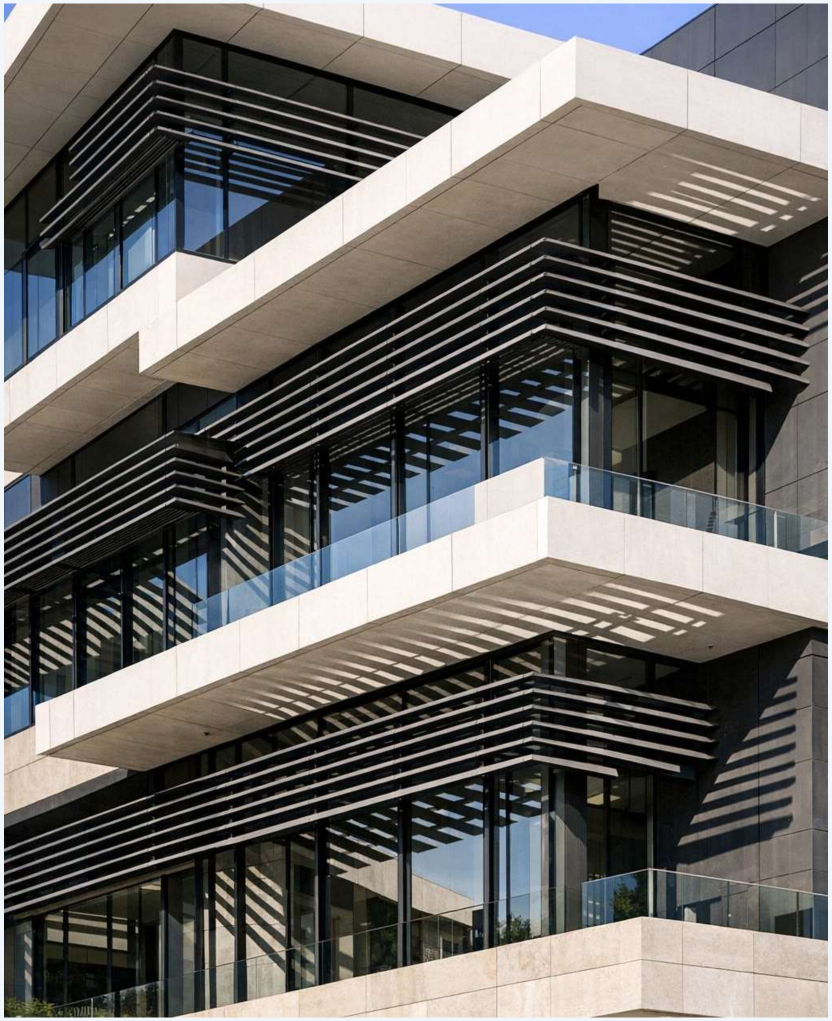
7. Overhangs and Louvers

Horizontal overhangs and adjustable louver systems are among the most effective passive shading strategies — blocking direct solar gain while preserving daylight and views.

- Blocks up to 90% of direct solar radiation on south-facing facades
- Reduces cooling loads by 20–35% when properly sized for latitude
- Maintains visual connection to the outdoors with controlled glare
- Applications: office buildings, schools, hospitals, residential balconies

Properly designed overhangs can eliminate the need for interior blinds on south façade (NH)s

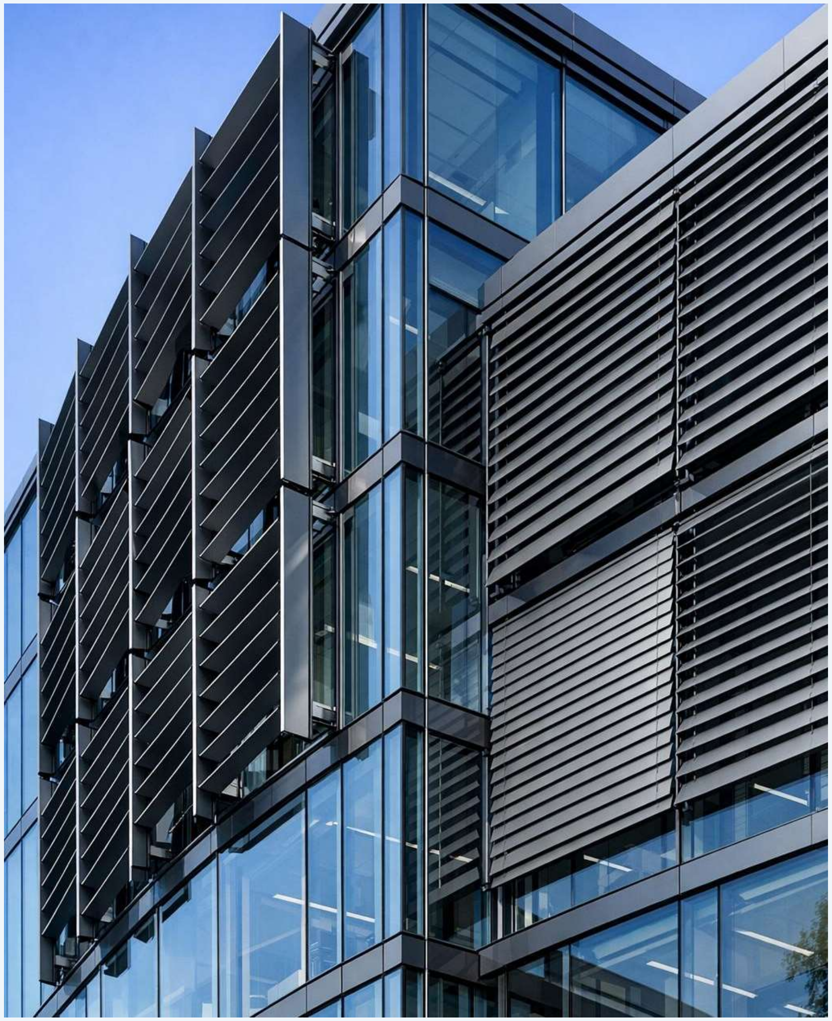


8. External Fins and Blinds

Vertical and angled external fins intercept low-angle sun on east and west facades — the orientations most difficult to shade with horizontal elements alone.

- Reduces solar heat gain on east/west facades by 40–60%
- Motorized systems adjust in real time to track sun position
- Enhances facade aesthetics with sculptural, rhythmic patterns
- Applications: glass curtain walls, atriums, airport terminals, high-rise offices

Automated external blinds outperform internal blinds by blocking heat before it enters



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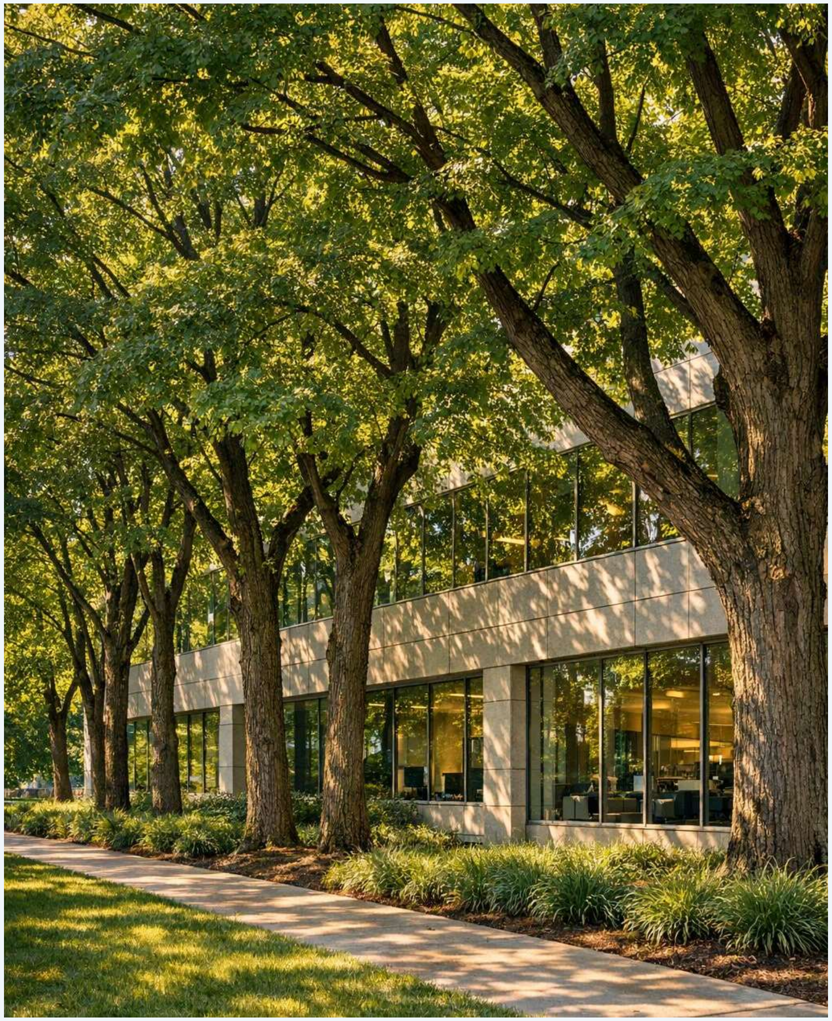
9. Deciduous Trees for Seasonal Shade

Strategically planted deciduous trees provide dense shade in summer while allowing solar gain in winter after leaf drop — nature's own adaptive shading system.

- Reduces air conditioning costs by 20–30% for shaded buildings
- Allows 70–90% of winter sunlight through bare branches
- Adds property value while improving streetscape character
- Applications: residential yards, campus grounds, car parks, streetside planting

Mature shade trees can lower surface temperatures beneath by up to 15°C



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10. Block Summer Sun, Allow Winter

Effective shading design exploits the seasonal difference in sun angle — using fixed geometry calibrated to block high summer sun while welcoming low winter rays.

- Fixed overhangs tuned to latitude block 80–95% of summer direct sun
- Low winter sun at 20–35° penetrates deep into interiors for passive heating
- Eliminates seasonal conflict between heating and cooling goals
- Applications: south-facing glazing design, sunspaces, passive solar homes

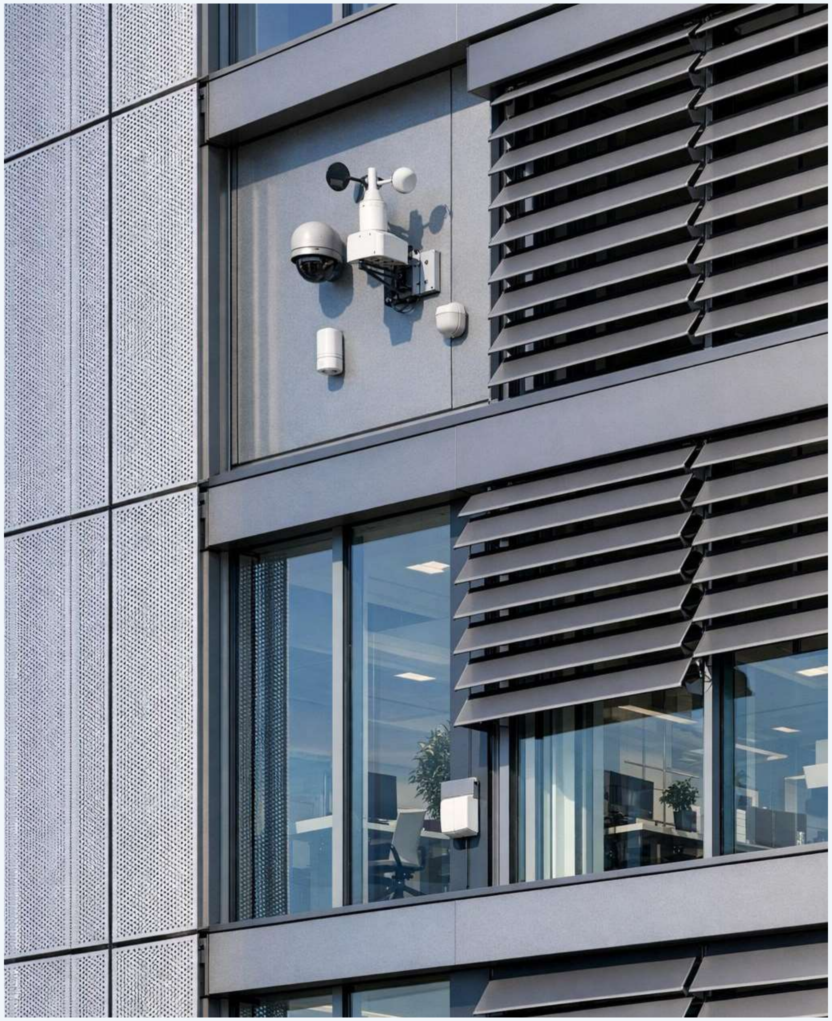
Latitude-optimized shading can reduce annual HVAC energy consumption by 25–40%

11. Dynamic vs. Fixed Approaches

Choosing between static shading elements and motorized responsive systems depends on budget, facade orientation, climate variability, and performance targets.

- Fixed systems: low maintenance, no energy use, reliable long-term performance
- Dynamic systems: real-time solar tracking, 20–30% more effective than fixed
- Hybrid approaches combine fixed overhangs with adjustable louvers or blinds
- Applications: smart facades, adaptive building skins, climate-responsive design

Dynamic shading integrated with BMS can optimize energy savings by up to 30% over fixed



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Natural Ventilation Systems

Cross-Ventilation	Openings on opposite facades create pressure-driven airflow through the building
Stack Effect	Warm air rises through atria and chimneys, drawing cool air in at lower levels
Solar Chimneys	Sun-heated vertical channels amplify the stack effect for enhanced air movement
Wind Towers	Capture and direct prevailing winds down into living spaces for passive cooling
Night Purging	Cool night air flushes stored heat from thermal mass, pre-cooling for the next day

These strategies can reduce or eliminate mechanical HVAC needs in suitable climates.

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Daylighting Technologies

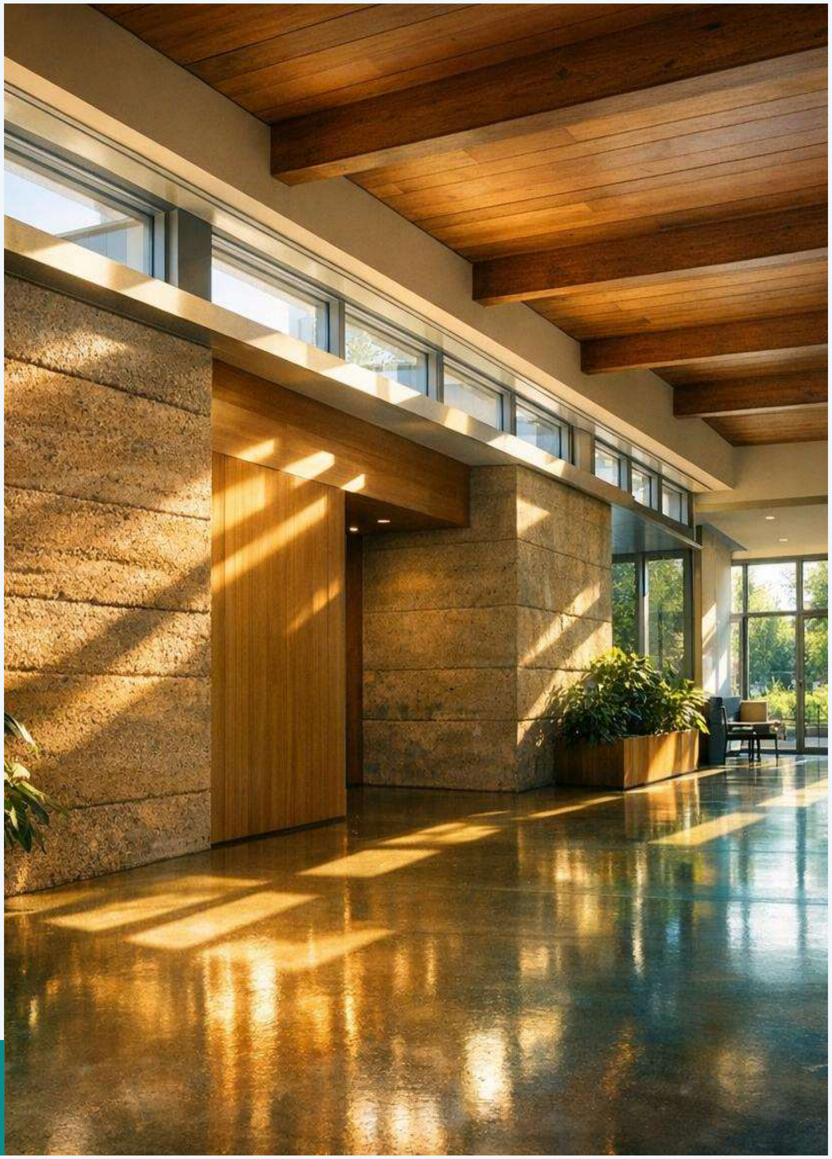
1 **Strategic Windows**
Sized and placed for optimal light penetration without glare

2 **Skylights and Clerestories**
Bring natural light deep into floor plans

3 **Light Shelves**
Reflect daylight deeper into rooms, reducing artificial lighting

4 **Atriums**
Multi-story light wells distribute daylight across floors

5 **Sensors and Controls**
Automated dimming minimizes artificial lighting when daylight is sufficient



Improves occupant well-being while cutting lighting energy 40–60%

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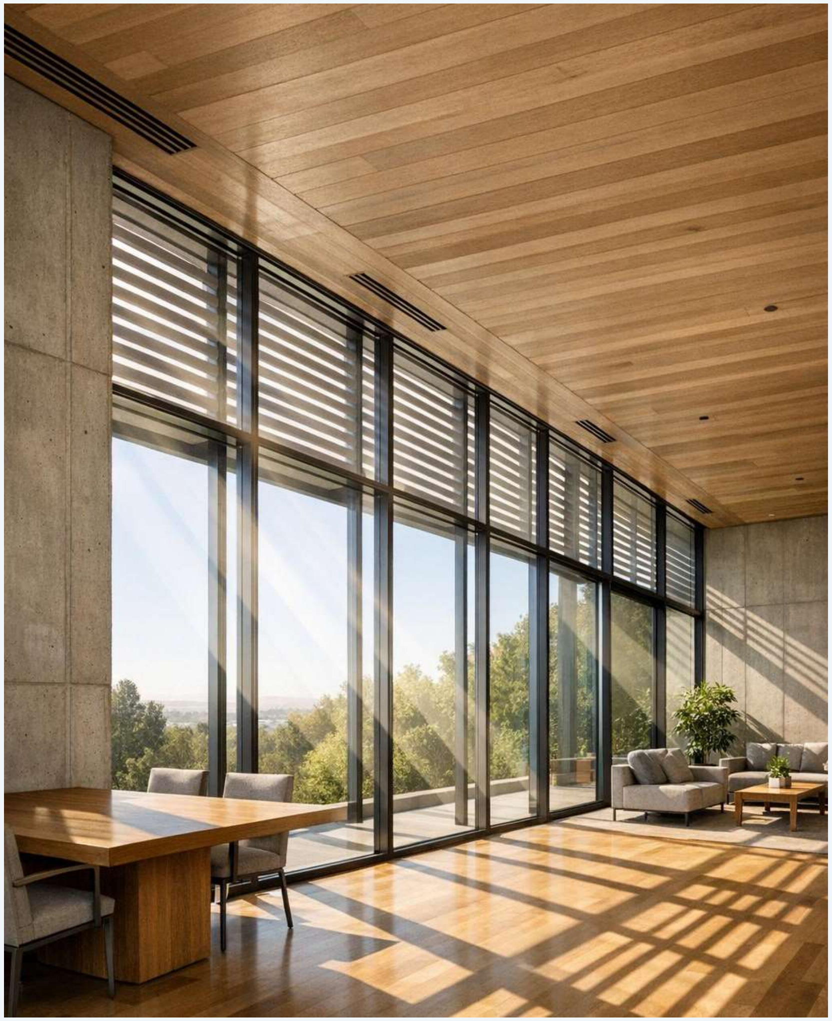
1. Strategic Windows

Carefully sized and positioned windows maximize natural light penetration while controlling glare — balancing visual comfort with energy performance.

- Reduce artificial lighting demand by up to 50%
- Improve occupant comfort and productivity
- Low-e coatings and SHGC tuning per facade
- Examples: floor-to-ceiling glazing, clerestory strips

Well-designed window strategies cut lighting energy costs by 40–60%



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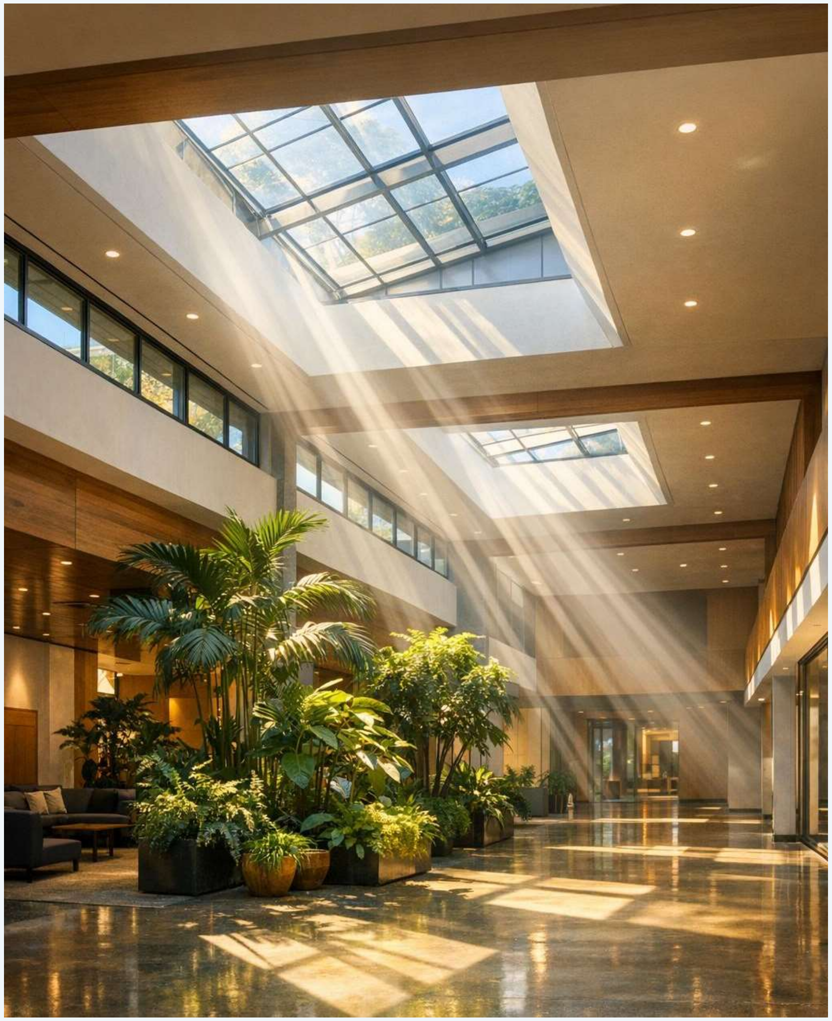
2. Skylights and Clerestories

Roof-mounted skylights and high clerestory windows bring natural light deep into floor plans where side windows cannot reach.

- Illuminate interior zones far from exterior walls
- Reduce dependence on electric ceiling lighting
- Tubular skylights serve narrow or windowless spaces
- Examples: ridge skylights, sawtooth roofs, light tubes

Skylights can deliver 3–5x more light per unit area than vertical windows



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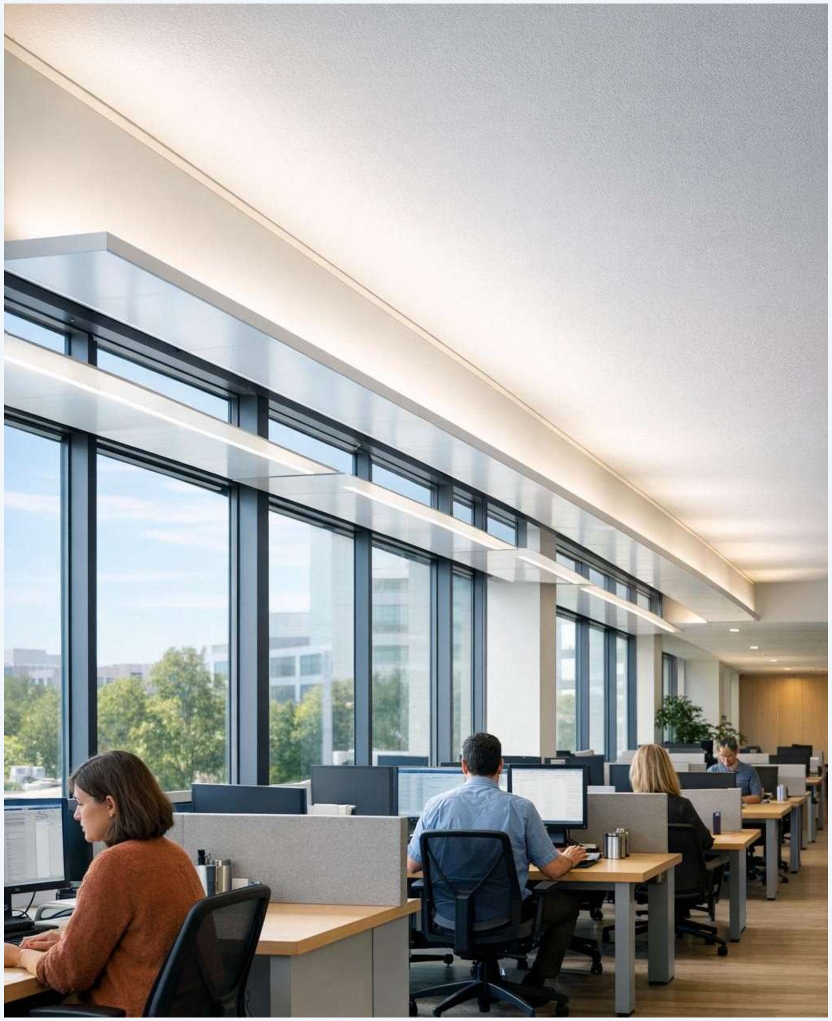
3. Light Shelves

Horizontal reflective surfaces mounted at window height bounce daylight deeper into rooms — extending the effective daylighting zone.

- Redirect sunlight onto ceilings for even distribution
- Reduce glare near windows while lighting rear zones
- Low-maintenance passive solution with no moving parts
- Examples: external shelves, internal reflectors,

Light shelves can extend useful daylight penetration by 1.5–2.5x deeper into a room



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4. Atriums & Light Wells

Multi-story light wells and glazed atriums distribute natural daylight across multiple floors and deep interior zones.

- Provide daylight to interior rooms on every floor
- Enable passive stack ventilation alongside lighting
- Create visually open, biophilic indoor environments
- Examples: central light courts, covered courtyards, sky gardens

Atriums can reduce artificial lighting loads by 30–50% in adjacent spaces

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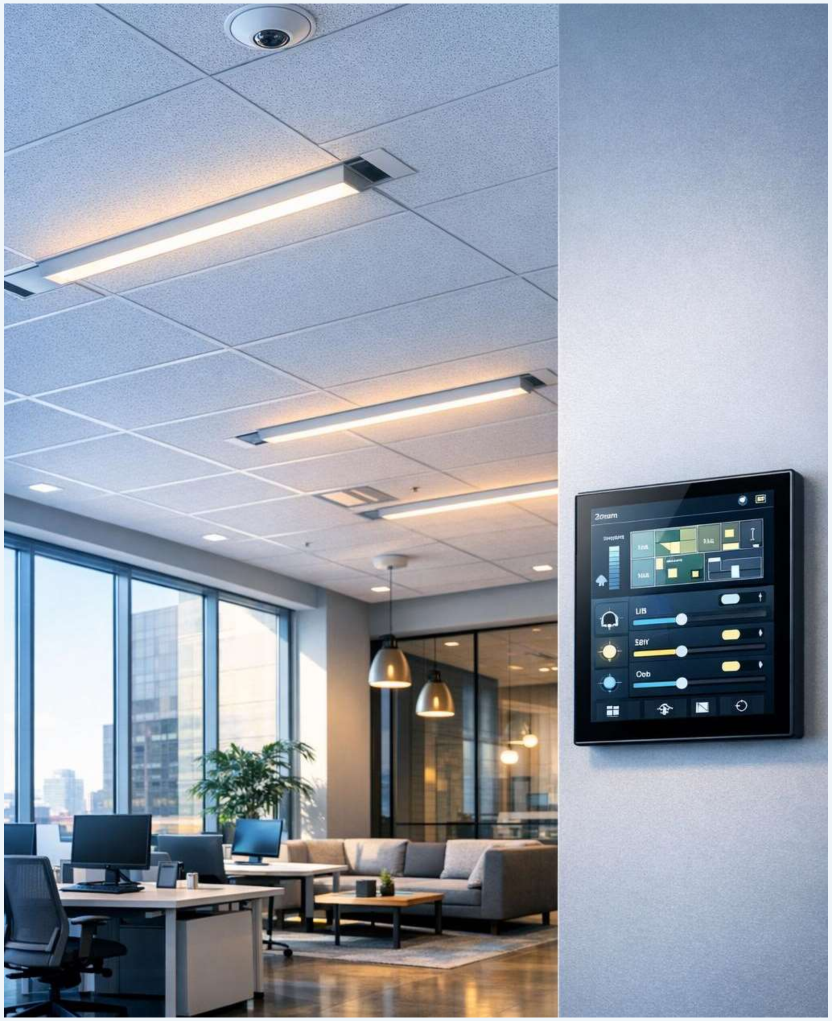
5. Sensors and Controls

Automated daylight sensors and dimming controls minimize artificial lighting when sufficient natural light is available.

- Photocell sensors adjust lighting in real time
- Occupancy sensors eliminate waste in empty rooms
- Integrate with building management systems for zoned control
- Examples: daylight harvesting, smart blinds, automated dimming

Smart lighting controls can achieve 20–40% additional energy savings



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Passive Cooling Techniques

Evaporative Cooling	Water evaporation absorbs heat from air — effective in dry climates with low humidity
Radiative Cooling	Surfaces emit thermal radiation to the cool sky, particularly effective at night
Earth Tubes	Underground air channels pre-cool ventilation air using stable ground temperatures (Geo-Thermal)
Phase-Change Materials	PCMs absorb/release latent heat at target temperatures, buffering thermal swings
Strategic Landscaping	Trees, water features, and ground cover create favorable microclimates around buildings

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Environmental Systems

Integrated environmental systems enhance NZEB performance beyond energy — addressing resilience, comfort, and ecological impact.

Water Bodies

1. Ponds (Rain Water Attenuation)
2. Fountains
3. Water walls provide evaporative cooling and thermal mass

Green Infrastructure

1. Integrated bioswales
2. Rain gardens
3. The Urban Jungle

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Chapter 4

Integration and

Case Studies

Holistic NZEB Design in Practice

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NZEB Case Studies

70%+	**Passive Solar Homes** South-oriented (NH) glazing, thermal mass floors, and overhangs achieve 70%+ heating reduction in mid-latitude climates
Net Zero	**Green-Certified NZEBs** Buildings combining thermal mass, natural ventilation, high insulation, and rooftop PV achieve net-zero operational energy
50-60%	**Adaptive Retrofits** Existing buildings upgraded with passive and active strategies and envelope improvements can reduce energy demand by 50–60%

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Benefits and Challenges

Benefits

- Dramatic energy savings (50–80%)
- Superior occupant thermal comfort
- Reduced operational costs long-term
- Lower carbon emissions
- Increased property value
- Grid independence and resilience

Challenges

- Climate-specific design tuning
- Higher upfront design effort
- Occupant behavior dependency
- Skilled workforce requirements
- Integration complexity
- Performance gap monitoring

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PART 2 - ACTIVE DESIGN STRATEGIES

The Role of Renewable Elements in NZEB Design

Harnessing Renewable Building Products and Active Strategies for Net Zero Energy Architecture

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Active Building Technologies for NZEB Design

Key technologies and systems that actively reduce energy consumption and generate renewable power:

1. **Envelope insulative building materials (SIPs)**
2. **Rooftop solar PV**
3. **Air-source heat pumps**
4. **LED lighting with smart controls**
5. **Heat recovery ventilation**
6. **High-performance insulation and glazing**
7. **Smart building management systems**
8. **Battery energy storage**
9. **Building-integrated photovoltaics (BIPV)**
10. **Geothermal heat pump systems**
11. **Demand-controlled ventilation**
12. **Water Recovery and Re-Use**

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1. Envelope and Insulation Strategies

A high-performance, airtight envelope with superior insulation is the single most impactful active strategy — minimizing conductive losses and gains year-round.

Airtight Envelope

- Minimize air leakage
- Continuous air barrier
- Blower door tested
- < 1.0 ACH50 target

Advanced Glazing

- Triple glazing standard
- Low SHGC where needed
- Tuned per orientation
- Low-e coatings

Insulation & Roofing

- Low U-values throughout
- Continuous insulation
- Cool/reflective roofs
- Thermal bridge-free

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Advantages of Products Manufactured from Renewable Materials for NZEB

1
Quality Control
Factory-controlled precision and consistency

2
Speed of Build
Reduced on-site construction time

3
Performance
Tested thermal and airtightness values

4
Sustainability
Less waste, lower embodied carbon

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2. Rooftop Solar PV

Advantages & Benefits

- Generates clean, renewable electricity directly on-site
- Reduces grid dependency and long-term energy costs
- Low maintenance with 25+ year lifespan
- Scalable from residential to large commercial installations
- Reduces peak demand charges and carbon emissions

Applications

- Commercial and residential rooftop arrays
- Carport and canopy-mounted solar systems
- Grid-tied systems with net metering
- Off-grid and hybrid energy systems for remote sites

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3. Air-Source Heat Pumps

Advantages & Benefits

- 300–400% efficiency (COP 3–4) vs. conventional heating
- Provides both heating and cooling from a single unit
- Lower carbon emissions than gas or oil boilers
- Minimal site disruption — no ground loops required
- Compatible with underfloor heating and radiator systems

Applications

- Residential space heating and domestic hot water
- Commercial HVAC in offices and retail spaces
- Retrofit replacement for fossil fuel boilers
- Integration with solar PV for near-zero operating cost

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4. LED Lighting with Smart Controls

Advantages & Benefits

- Up to 80% energy savings vs. traditional lighting
- Long lifespan of 50,000+ hours reduces maintenance
- Occupancy and daylight sensors eliminate waste
- Tunable color temperature supports circadian wellbeing
- Instant-on with no warm-up time required

Applications

- Office and commercial interior lighting
- Facade and architectural accent lighting
- Warehouse and industrial high-bay applications
- Smart campus and building-wide automation

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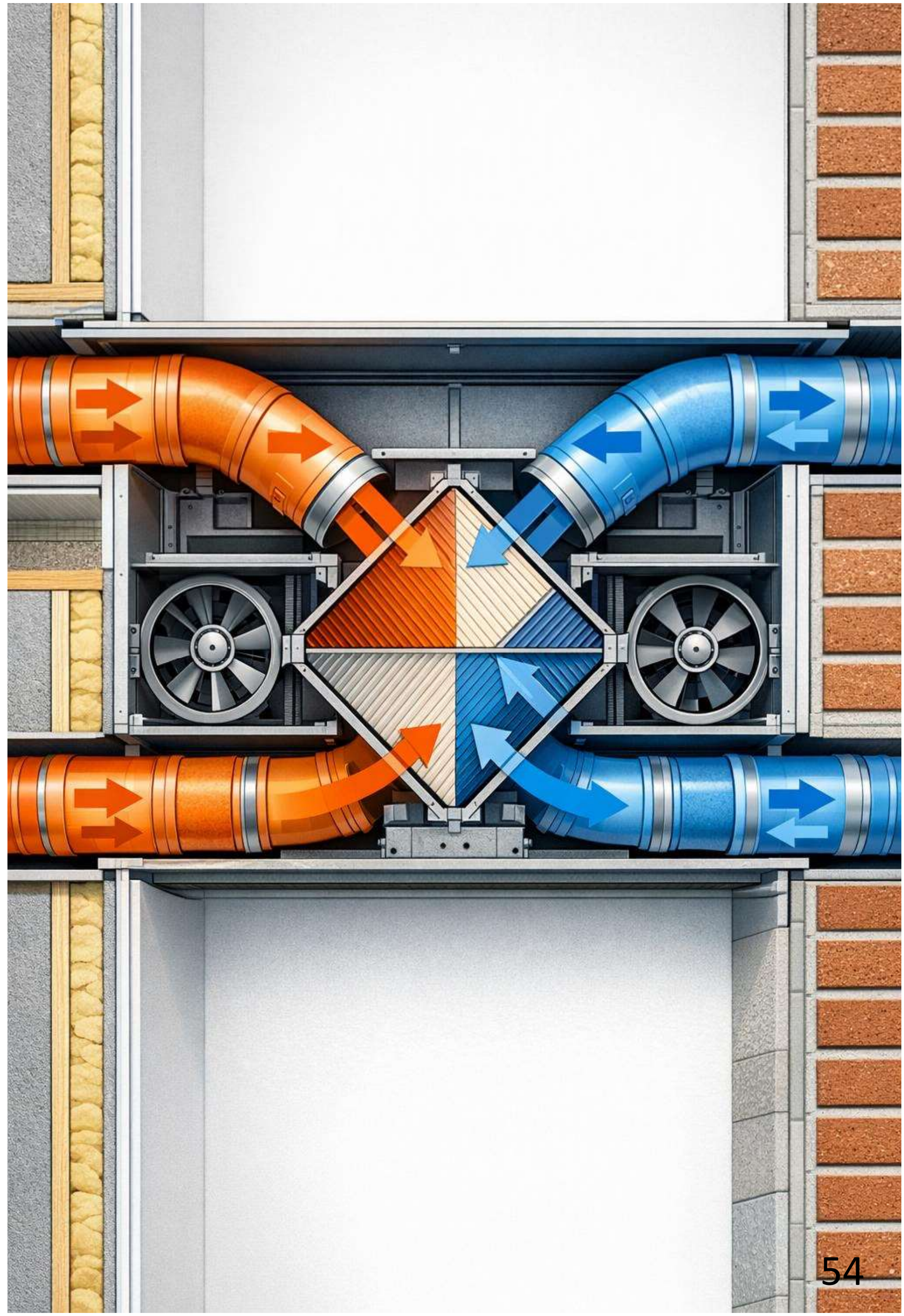
5. Heat Recovery Ventilation

Advantages & Benefits

- Recovers up to 90% of exhaust air heat energy
- Maintains fresh indoor air in airtight buildings
- Reduces heating and cooling loads significantly
- Filters incoming air, reducing allergens and pollutants
- Essential for Passive House and NZEB compliance

Applications

- Residential whole-house ventilation systems
- Commercial office and classroom ventilation
- Hospital and laboratory clean-air environments
- Integration with demand-controlled ventilation



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6. High-Performance Insulation and Glazing

Advantages & Benefits

- Dramatically reduces conductive heat loss and gain
- Triple glazing achieves U-values below 0.8 W/m^2K
- Low-e coatings control solar heat gain per orientation
- Continuous insulation eliminates thermal bridges
- Enhances acoustic performance and occupant comfort

Applications

- High-performance building envelopes and curtain walls
- Retrofit upgrades to existing facades and windows
- Cold-climate residential and commercial buildings
- Passive House and NZEB-certified construction

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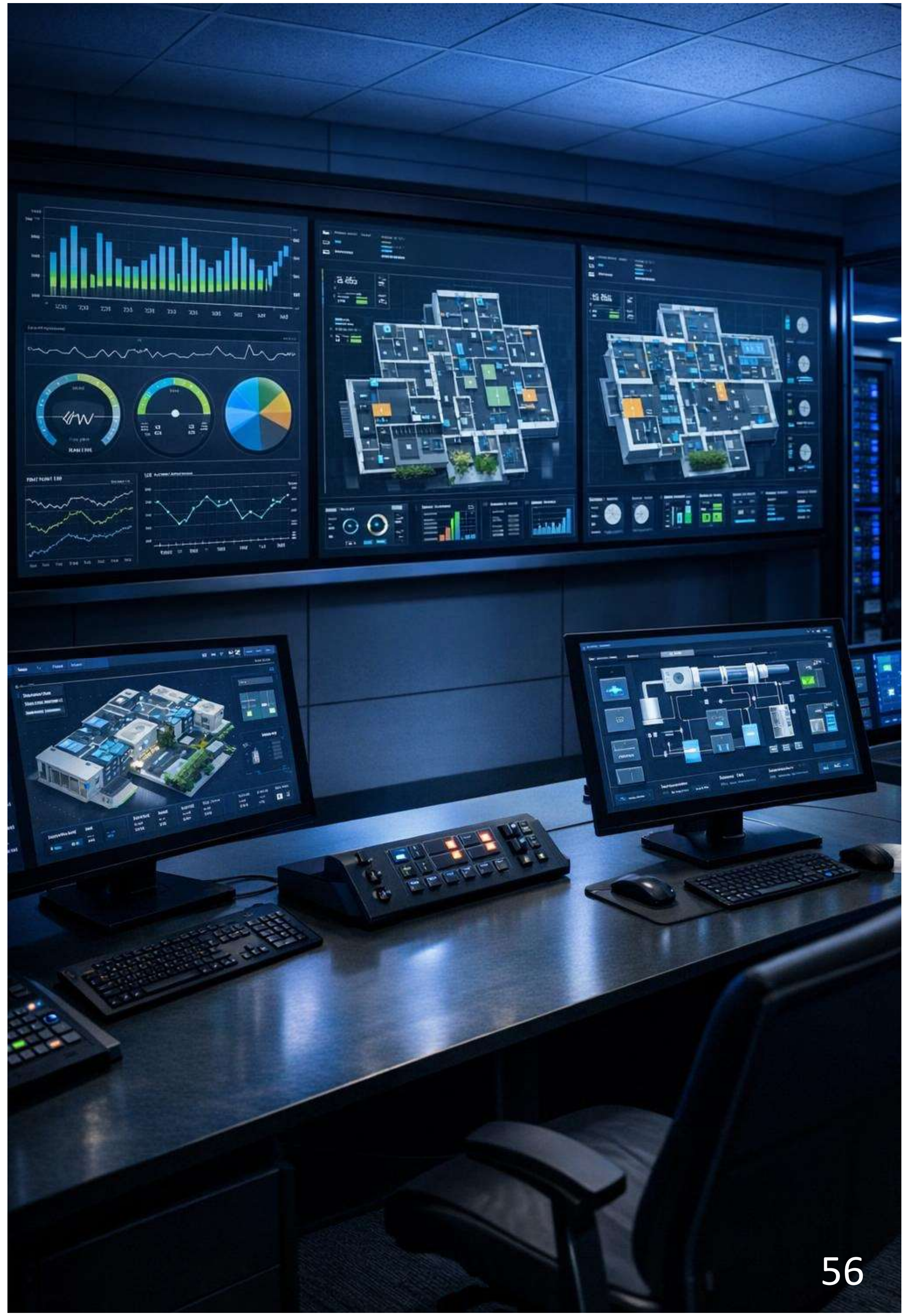
7. Smart Building Management Systems

Advantages & Benefits

- Centralized real-time monitoring of all building systems
- AI-driven optimization reduces energy waste by 20–30%
- Predictive maintenance reduces equipment downtime
- Data analytics enable continuous performance improvement
- Seamless integration of HVAC, lighting, and renewables

Applications

- Large commercial and institutional buildings
- Campus-wide energy management
- Demand response and grid interaction management
- Occupant comfort optimization via IoT sensor networks



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8. Battery Energy Storage

Advantages & Benefits

- Stores excess solar energy for peak demand use
- Provides backup power during grid outages
- Reduces electricity costs through peak shaving
- Enables greater self-consumption of on-site renewables
- Supports grid stability through demand response

Applications

- Residential solar-plus-storage systems
- Commercial peak demand management
- Microgrid and off-grid power solutions
- Integration with EV charging infrastructure

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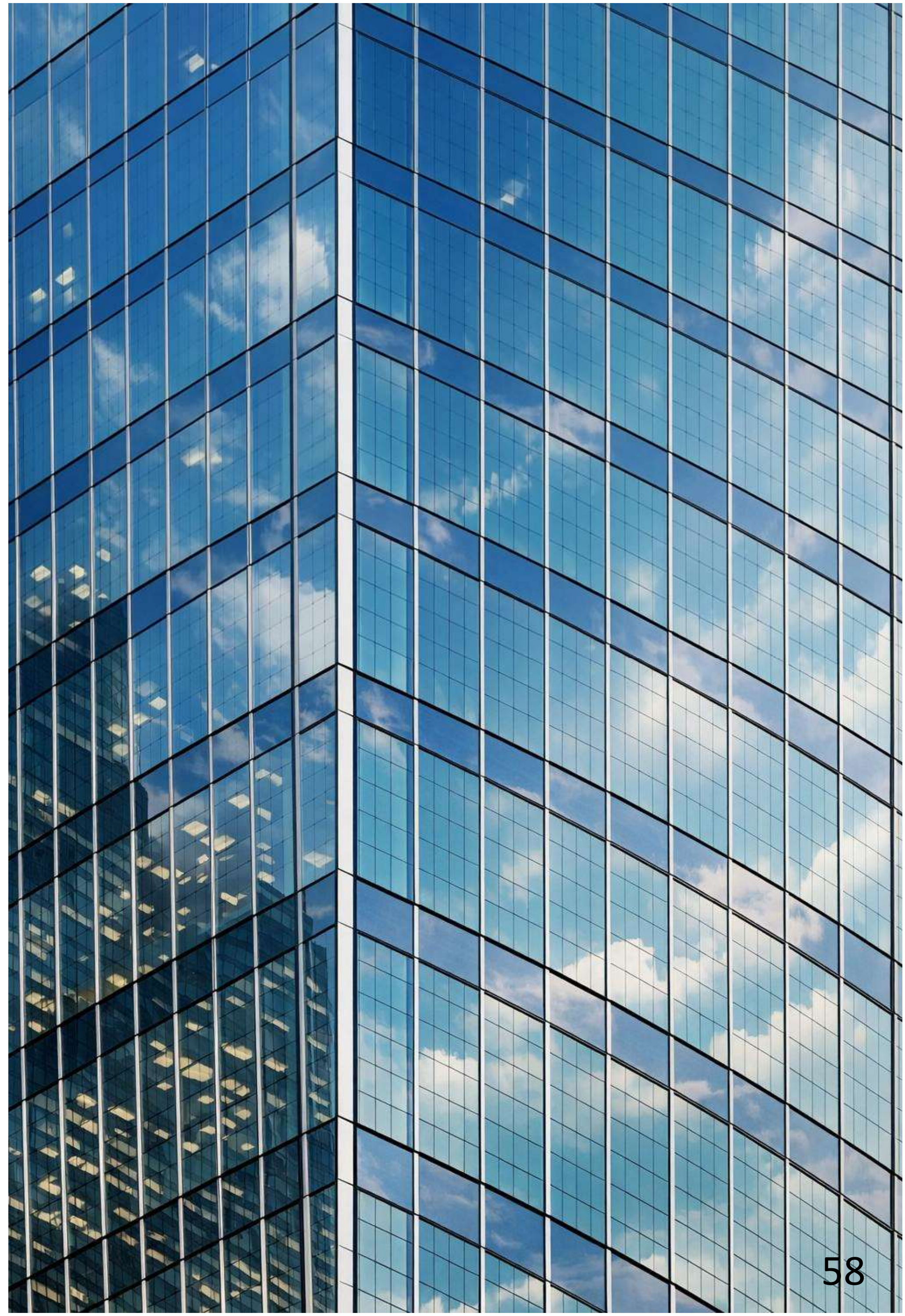
9. Building-Integrated Photovoltaics (BIPV)

Advantages & Benefits

- Replaces conventional cladding, reducing total cost
- Generates electricity from facades, roofs, and skylights
- Aesthetically seamless — no visible bolt-on panels
- Maximizes energy-generating surface area
- Available as solar glass, tiles, cladding, and shingles

Applications

- Curtain wall facades on commercial high-rises
- Solar roof tiles for residential architecture
- Skylights and atria with semi-transparent solar glass
- Heritage and design-sensitive renovation projects



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10. Geothermal Heat Pump Systems

Advantages & Benefits

- Stable ground temperature yields COP of 4–5 year-round
- Provides heating, cooling, and hot water from one system
- Lowest operating cost of any HVAC technology
- 50+ year ground loop lifespan with minimal maintenance
- Zero on-site emissions and very low noise levels

Applications

- Large commercial and institutional campuses
- Residential ground-source heating in cold climates
- District heating and cooling networks
- Integration with thermal storage for load shifting

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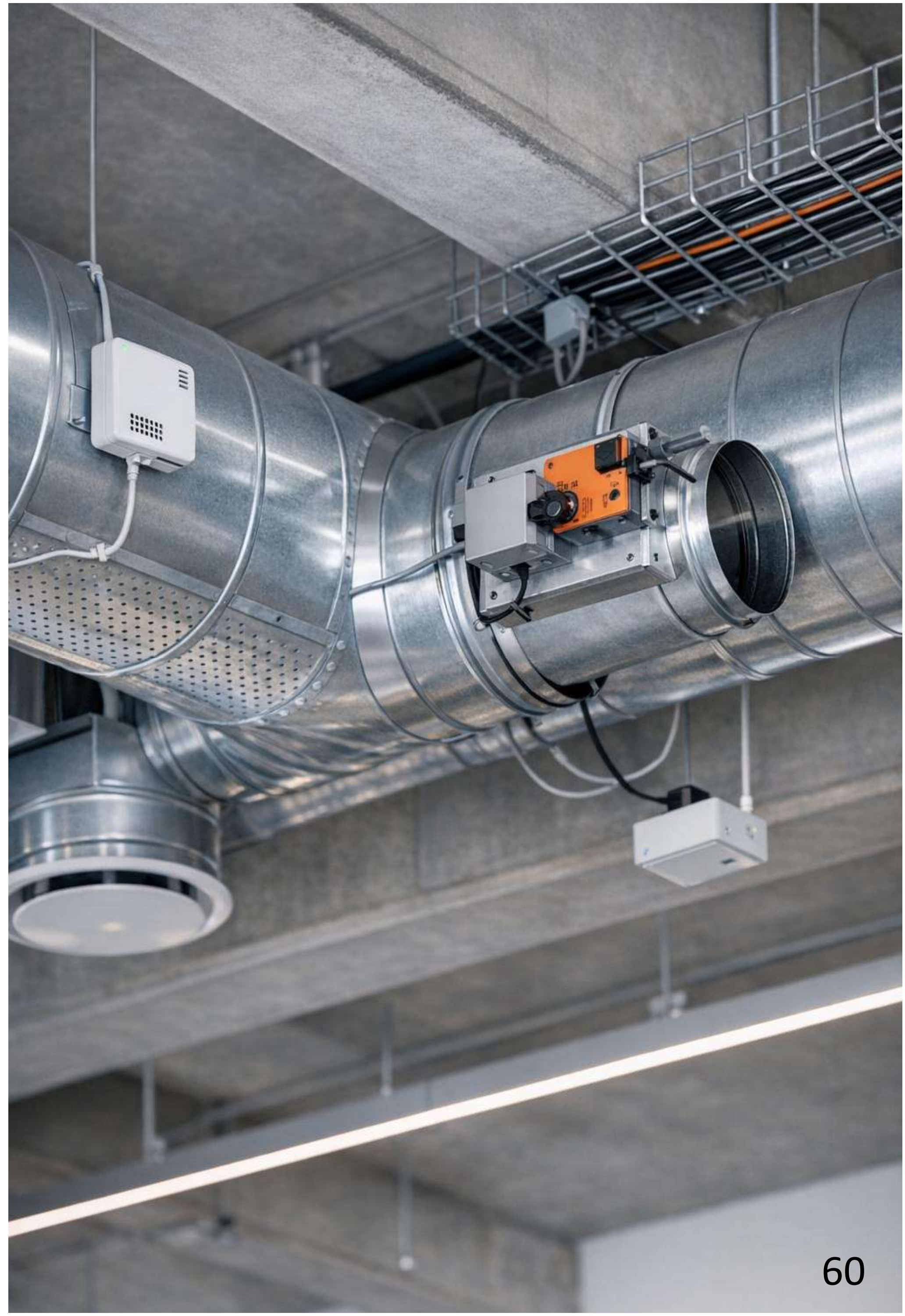
11. Demand-Controlled Ventilation

Advantages & Benefits

- Adjusts airflow based on occupancy and CO_2 levels
- Reduces ventilation energy use by 30–60%
- Maintains optimal indoor air quality automatically
- Prevents over-ventilation in partially occupied spaces
- Works with existing HVAC via smart retrofits

Applications

- Open-plan offices with variable occupancy
- Conference rooms, classrooms, and auditoriums
- Retail spaces and shopping centres
- Integration with BMS and heat recovery systems



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12. Water Recovery and Re-Use

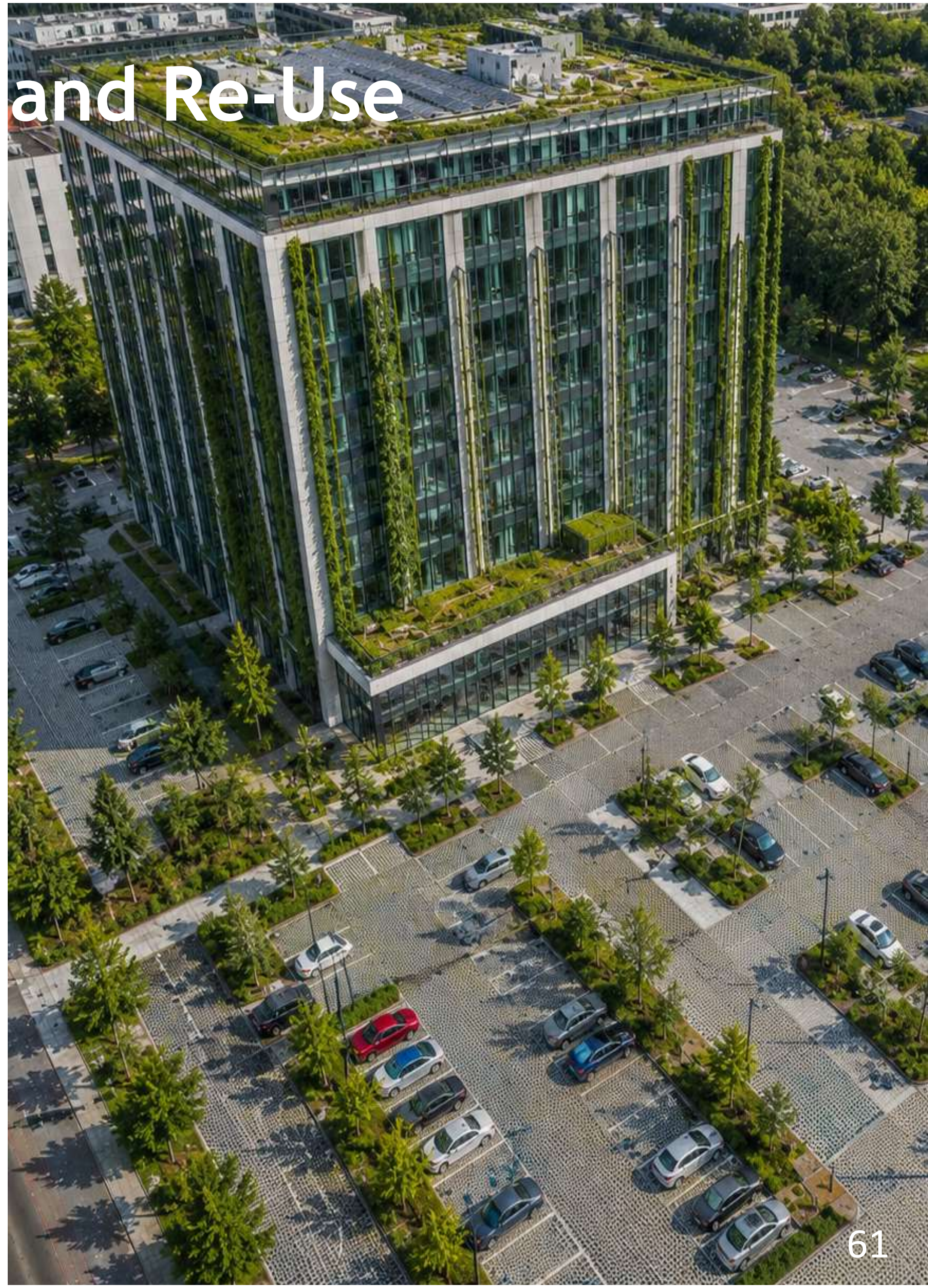
Integrated water and environmental systems enhance NZEB performance beyond energy — addressing resilience, comfort, and ecological impact.

Rainwater Harvesting & Attenuation

Collect, filter, attenuate and reuse rainwater for non-potable applications and landscape irrigation by means of permeable surfaces for site resilience and biodiversity

Greywater Recycling

Treat and reuse wastewater with heat recovery to reduce water consumption and energy



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Conclusion and Future Outlook

Building in Harmony with Nature

Natural elements are the foundation of truly sustainable NZEBs. By respecting Milankovitch-scale climate context, local insolation patterns, and deploying passive technologies, we create buildings in harmony with nature.

Prioritize passive-first design for a net-zero future.

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Integrating Both Passive & Active Strategies into NZEB Design

1
Climate Analysis
Assess local conditions

2
Passive Measures
Orientation, mass, shading

3
Efficient Systems
Optimize active systems

4
Renewables
PV, solar thermal, etc.

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Thank You

Principles, Strategies, and Technologies for Sustainable Architecture

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